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ON TORPEDO BOATS AND LIGHT YACHTS FOR HIGH SPEED STEAM NAVIGATION.

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I.

THE services for which torpedo boats and steam yachts are required render it imperative that they should be capable of attaining high speeds, that they should work silently, and that they should be of limited dimensions. They must also possess great propelling power in proportion to their total weight or displacement; that is to say, whilst the propelling power must be ample, the displacement must be reduced to a minimum. It will be expedient to examine how the two conditions of lightness and sufficient power may best be obtained, and what practical means have hitherto been adopted for giving effect to them. For this purpose the total weight or displacement of a vessel may be conveniently divided into three components: 1st. The structural hull, as defined by the late Mr. Froude; 2nd. The propelling machinery and apparatus; 3d. The load.

The third of these, the load, is comparatively insignificant. In torpedo-boats the load consists of torpedoes and the fighting gear; in steam yachts, the cabin fittings. The first component, the hull, depends practically on the second, and it cannot safely be made less in weight than a certain fraction, well defined, of the sum of the two other components. Most progress is to be hoped, therefore, from the treatment of the second component, and in reducing the weight of the propelling machinery and apparatus, the weight of the hull, too, may be reduced.

The general conditions on which the reduction of the weight and the volume of the propelling machinery and apparatus is dependent, may be briefly summarised as follows:—Rapid combustion of fuel, subdivided flue way, in order to multiply the heating surface; high steam pressure, and high speed of engine—speed of revolution as well as of piston, particularly the former as the more important of the two. Such are the characteristic features of the locomotive engine, in which they were first developed, and it may be useful to sketch the progress of the locomotive as the embodiment of extreme lightness and concentration of power.

The earliest locomotives, used for working coal trains on tramways, were little more than reflections of the ordinary practice of the stationary engines of the time, in which the element of weight was not in itself objectionable. The fires

were urged simply by the natural draught of the chimney, assisted occasionally by the exhaust steam turned into the chimney; and the heating surface consisted of the iron-plate furnace and the iron flue. Under these circumstances, from 30 lbs. to 40 lbs. of coal were consumed per square foot of fire-grate per hour, whilst the quantity of water evaporated per lb. of coal did not amount to more than from 3½ lbs. to 4 lbs., and the pressure of steam in the boiler did not probably exceed 15 lbs. or 20 lbs. per square inch. Suffice it to state, in addition, that in the course of improvement the current of hot gases was subdivided, by the multitubular flue, into numerous streams enclosed within extensively developed surfaces, as initiated in the historic "Rocket" locomotive. But the draught, and consequently the rate of combustion of the fuel, were vastly accelerated by the introduction of the blast pipe for directing the exhaust steam up the chimney, insomuch that from 50 lbs. to 100 lbs., and even still higher rates of combustion of fuel per square foot of fire grate are now practiced; that higher pressures have adopted, augmented progressively from 50 lbs, to 140 lbs. per square inch; and that the cylinders have universally been connected directly to the driving or crank axle, making from two hundred to two hundred and fifty revolutions per minute, with speeds of piston of from 600 to 1,000 feet per minute.

With such a practical example of combined lightness and power, it followed naturally that much of what had been matured in the practice of the locomotive on railways was adopted for the propulsion of high-speed vessels of limited dimensions on water. But there are at the same time important differences in the circumstances of the two cases under which the engines work. In water, the engines are required to put forth their full power continuously for long periods, for there is nothing corresponding to a level road or a bank sloping downwards, after an ascent on an incline, to relieve the stress. Full power is unremittingly required to keep up full speed, whilst the water ever assumes the form of an inclined plane upward. Boiler power is, under such circumstances, continually tasked to its utmost capacity, and a larger boiler is required for cylinders of given dimensions than is necessary under the circumstances of railway traction. Moreover, for surface-condensing engines, from which the soft water of condensation is returned to the boiler, a greater proportion of steam room is necessary. The bearing surfaces of the engines, likewise, are required to be larger, in order to keep the working parts cool.

In the swift American river boats high-pressure steam is used, either with or without condensation, whilst the fires are forced by means of a fan blast or a blow pipe in the chimney. But the high speeds of which they are capable have, for the most part, been effected with great dimensions; for, with large paddle wheels and long strokes, their engines are necessarily heavy and bulky, and although a considerable speed of piston is attained in virtue of the long stroke, a high speed of revolution is impracticable.

The large space occupied by paddle engines, and the great weight involved in their construction, were partially reduced by the introduction of oscillating cylinders, though here a difficulty was encountered in employing steam of high pressure; and with relatively low pressure and low speed of pistons, cylinders of large capacity were unavoidable. Many swift paddle steamers have been built with oscillating cylinders, and they are beautiful structures of their kind; but the cylinders are so large as to occupy nearly all the mid-ship sectional area of the vessel. To make way for higher pressures with paddle engines, many constructors have returned to fixed cylinders, with connecting rods; but when such engines are, for the sake of length, placed in an inclined position within a vessel, they are open to the objection of occupying considerable room, besides the fundamental objection of heaviness in comparison to the work that can be done with them.

When the screw came to the front as a rival to the paddle, a new opening was made for augmenting the speed of marine engines, although at first the opportunity was not embraced, seeing that intermediate gearing was employed to bring up the speed of revolution of the screw, whilst the speed of the engine remained relatively low. But the reducing

gear was ultimately suppressed, and the screw was driven direct by the engines, which were connected to the screw shaft; and compact engines of quick revolution, with high speed of pistons, worked under high pressures, were brought into successful operation.

Under the stress of competition, the demand for economy of the space occupied by the boiler and the coals was keenly felt, most of all for long voyages, for which the first ocean vessels working at high pressure were built. Besides, the higher the pressure, the smaller may be the boiler, at least so far as the steam room may be proportioned; and there does not appear to be in use at present better boilers than those of the locomotive type, which are light and trustworthy, for the service of torpedo boats and steam yachts. It is to be noted, nevertheless, that a limit is imposed on the degree of pressure that may be available, by the limit of temperature of the steam, which increases with the pressure at which an engine can be worked.

The Herreshoff boiler claims some notice, as it is light, and is of small capacity, containing designedly but a limited quantity of water, in itself conducive to safety. This boiler consists of little else than a coil, by which the water supply is connected with the steam pipe and separator. The feed water, introduced at the top, falls by gravitation, and its fall is accelerated by the stream of steam disengaged in the course of its passage downwards, by the only way out in fact. The boiler appears, at first sight, to promise good results. But so even a balance is required between the fire and the feed water that the boiler is not likely to be maintained, even for a short time, in the most favorable conditions for work; and should the supply of water fall short of the normal quantity, the steam would be highly superheated, and the engines would be seriously damaged. By an excess of water supply, on the contrary, the heat of the fire would be taken up, without the performance of useful work, and with a corresponding loss of economy. But the question remains, What are the merits of the Herreshoff boiler, under the best conditions that can be maintained, with a small excess of feed water?

For the purpose of forcing the draught of marine boilers, the fan appears to be the most convenient instrument. Fans have occasionally been set to work in the flues, operating by suction on the products of combustion after they have left the boiler; but they could not last long there, exposed to high temperatures. The author prefers to stimulate the draught by forcing air into the stokehole. By this means, a better action is maintained, whilst at the same time the stokehole is kept moderately cool. He devised the fan blast in this form for the boilers of the yacht "Gitana," built by him in 1876, and it has been found to work efficiently. The pressure of the blast used for the boilers of the "Gitana" and other boats of its class is measured by a column of water, from 3 inches to 6 inches high. The greater part of the pressure is exerted in overcoming the resistance of the flue tubes of the boiler. The degree of blast pressure that may safely be employed depends very much on the length and the diameter of the tubes, as well as upon the width of the water interspaces between them. If large, flue tubes were used in a boiler, the author is of opinion that the limits of safety might easily be exceeded; and although the maintenance of a plenum in the stokehole is satisfactory in operation, he feels that it must be employed with caution, particularly in its application to boilers having small fire grates and large sectional area of flue ways. The risk of damage would, of course, be greatly increased by internal deposits.

In using steam of high pressure, the compound engine is generally adopted, for stationary as well as for marine propulsion; though in locomotive practice the cylinders, as yet, have but rarely been compounded. There are three advantages attendant on the employment of compound engines compared with single-cylinder engines—a more nearly uniform distribution of pressure during the stroke of the piston, accompanied by a better distribution of tangential pressure on the crank pins; a diminished range of temperature in each cylinder, and comparative simplicity of valve gear. A relatively high speed of engine may be taken as favorable for economy of steam, in consequence of the smaller area of cooling surface in the

cylinders of high-speed engines than in those of low-speed engines, exerting equal power; as well as of the smaller circumferential passages for accidental leakage of steam about the pistons and the valves.

The proportion of expansion to which steam should be worked in compound engines, for the purpose of attaining the greatest economy of steam and fuel, was made the subject of many carefully-conducted experiments on the compound engines of the U. S. revenue steamer "Rush," in which the cylinders were thoroughly steam-jacketed with steam of 82 lbs. per square inch initial pressure. The most economical ratio of total expansion was found to be 6.22; and on board the "Dexter," where the engines had single cylinders without any steam jackets, the best ratio of expansion was $3\frac{1}{2}$.

Having considered, in general terms, the conditions necessary for light propelling machinery, the author will now examine the relative weight and form of hull best adapted for carrying the load and the machinery. The weight of the hull depends principally, as already stated, upon the gross amount of weight to be carried. It is not much affected, within moderate limits of variation, by the proportions of the hull; but when the proportion of the length to the depth is increased, the weight of material necessary to secure sufficient longitudinal strength is inevitably also increased.

The shape of hull that should be adopted is the result of the most suitable compromise between several requirements, each of which, taken separately, dictates unfortunately a special form differing from the other forms. Speed is, for torpedo boats, a requirement of the first importance. The next is handiness, and this demands that the length should be shortened as much as is practicable. The element of frictional skin-resistance of the submerged surface of the hull should be reduced as much as possible. For this object, by cambering the keel, the area of the immersed surface and that of the dead wood is much lessened. The handiness of the vessel for turning is, at the same time, increased by diminishing the depth at the ends.

To augment the stability, the width of the deck may be increased considerably beyond the width measured at the water line. The increase of bulk thus effected augments the righting force, when any considerable inclination of the vessel from the vertical is reached, without impairing the speed. The freeboard, also, must be such that the angle at which stability vanishes is very large, so that there may not be any danger of capsizing. The suddenness with which waves are encountered when the vessel is in rapid motion requires that the form of the bows of the boat above water be not too bluff, otherwise the shocks which are sustained may endanger the structure. Nevertheless, considerable bulk must be maintained in the bows, in order to lift the forward part of the vessel. This lifting is greatly facilitated by making the ends light, and concentrating the load, as far as may be, about the center of the vessel

The most favorable position for the propeller for high speeds, is astern of the rudder; but, as little loss of speed is entailed by reversing the relative positions of the rudder and the screw, and as the steering qualities are improved by so doing, it is frequently preferred to place the screw in advance of the rudder, although the effect of the transposition is somewhat to increase the length and the weight of the boat at the stern. The question of immersion of the propeller is also important; but it is not easy of estimation in vessels of high speed relative to their size, as the change of trim involved by high speed frequently provides sufficient immersion, although when the vessel is at rest, immersion may not be complete. If the propeller breaks the surface of the water while in action, the air drawn down, in consequence, causes a greater loss than might be expected. Experiments were lately made by the author on a mode propeller, the performance of which was carefully noted, both when it was totally immersed and when it was working under such a state of immersion that it just broke the surface. In the first case, the useful effect was equal to about seven-tenths of the power expended, and the action was perfectly steady and easily recorded. In the second case, however, the condition of working varied so much that it was only with difficulty that the

efficiency could be ascertained, and no precise value for the efficiency could be given, except in so far that a considerable loss was proved, for it did not appear that the efficiency exceeded five-tenths of the power expended.

For small vessels, it does not seem worth while to discuss the question of using one propeller or two propellers, as twin engines would involve so many duplicate pieces, that they could only be employed where the advantages to be derived from their use would be very great. For large vessels, they seem to be most desirable.

The relative position of vessels in motion, in the system of waves caused by and surrounding them, is of great interest, as it throws light on the cause of the low rate at which the resistance of hulls increases at relatively high speeds. It was ascertained by Mr. Bramwell in experimenting with the "Miranda" that a wave crest, situated near the stem at ordinary speeds, moved gradually towards the center of the vessel as the speed was increased to the maximum attained by the vessel. Mr. R. E. Froude has found that this wave crest is the foremost in the system, and that the advance of a vessel upon this crest has the effect of diminishing the wave slope which is opposed to the vessel's motion.

The author will now describe three boats built by his firm:—1, The yacht "Gitana," for the Baroness Adolphe Rothschild, for excursions on Lake Leman; 2, A first-class torpedo-boat, for the English Government, very similar to the "Lightning," the earliest boat of the class; 3, A second-class torpedo-boat, smaller than the preceding, many of which have been constructed for the English Government.

THE YACHT "GITANA."—Fig 1.

The length of the hull at the water-line is 86 feet, and the extreme length is 90 feet; the breadth of beam at the water-line is 10 feet 6 inches, and the extreme beam is 13 feet 2 inches. The draught of water is 4 feet aft, and 1 foot 1½ inch forward. The displacement is about 29 tons.

The engines are compound, condensing by injection, with an intermediate receiver. There are three cylinders, comprising a 13½-inch high-pressure cylin-

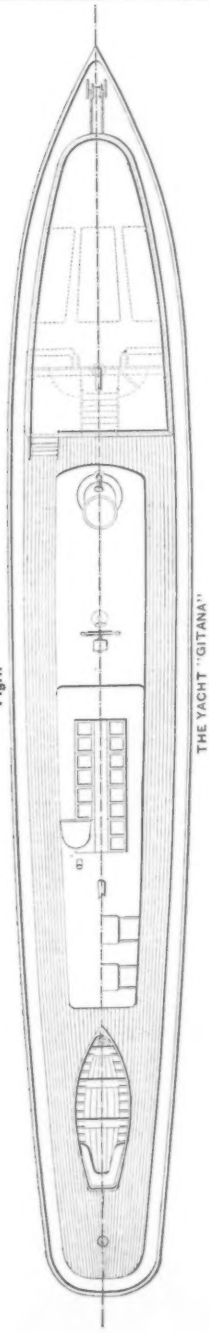


Fig. 1. THE YACHT "GITANA"

der, and two 15-inch low-pressure cylinders, with a stroke of 16 inches, working on three cranks placed at equal angles. The air-pump is 23 inches in diameter, with a stroke of 3 inches, and is worked by levers from the high-pressure cylinder. The feed pump is double-acting, $2\frac{3}{4}$ inches in diameter, and is worked directly by a steam cylinder, with a stroke of 7 inches. There is, in addition, a Giffard injector of 5 millimeters. The fan for blowing the fire is $3\frac{1}{2}$ feet in diameter, and is driven directly from a 5-inch steam cylinder, with a stroke of 3 inches, making about nine hundred revolutions per minute.

The propeller (Thornycroft's patent) is a screw of three blades, $5\frac{1}{4}$ feet in diameter, with a pitch of $8\frac{1}{2}$ feet; it is placed abaft the rudder.

The boiler is of the locomotive type, having a working pressure of 120 lbs. per square inch. The fire grate has an area of 16.2 square feet. There are one hundred and niety-seven flue-tubes, each $1\frac{3}{4}$ in diameter externally, and 8 feet $0\frac{1}{2}$ inch long. The heating surface of the fire box is 52 square feet, and of the tubes 653 square feet, together 705 square feet of heating surface.

The slide valves are so arranged as to cut off steam earlier in the stroke of the low-pressure cylinders than in that of the high-pressure cylinder, in order to equalize, as nearly as possible, the work between the three cylinders.

The framing of the main engine consists of small steel columns, directly connecting the cylinders with the bedplate, and placed as near to the main bearings as practicable. These columns are braced together near the center of their length, and are only adapted to resist vertical forces. The framing depends for transverse stability on its connection with the hull, to which the cylinders, and the lower ends of the guide bars, are fastened by stays.

For securing lightness of moving parts, the pistons are of wrought steel; the piston rods and connecting rods are also of steel, the piston rods being bored out. The cranks, the crank pins, and the lower halves of the connecting rods, are balanced by cast-iron balance weights, secured to the cranks by steel bolts.

The proportions of the blowing engine are unusual, a great length of bearings having been given. The combined length of the main bearings is 18 inches, their diameter being 2 inches; whilst the diameter of the steam cylinder is only 5 inches. The crank-pin is 4 inches long by two inches in diameter. The disk of the fan revolves within the engine room, without any external casing. It takes air in at one side only, from a large tube leading from the deck, and delivers it all round the circumference of the disc, without inconvenience. The shaft of this engine is fitted with thrust-collars to resist the unbalanced pressure of the air on the disc. Engines of this pattern have been worked at a speed of seventeen hundred revolutions per minute, or fifty-six strokes per second, without damage.

In estimating the effects of rapid change in the direction of stress on the journals of engines working at high speed, the author is of opinion that sufficient importance has not, in general, been attached to the fact that the lubricant has to sustain the pressure for but a very short time in one direction. This he considers is the principal reason why high-speed engines have so much less wear and tear than many persons appear to expect. It is, nevertheless, most important that correct adjustment should be maintained in order to secure good working results.

FIRST-CLASS TORPEDO-BOAT—Fig. 2.

This boat is 87 feet in length, with a breadth of beam of $10\frac{1}{2}$ feet. The draught is 1 foot 6 inches forward, and 5 feet 2 inches aft, with a displacement of 32.4 tons. The engines are compound, with an intermediate receiver, having a $12\frac{3}{4}$-inch high-pressure cylinder, and a low pressure cylinder $20\frac{7}{8}$ inches in diameter, with a stroke of 12 inches. The cranks are at right angles. The air pump is worked by levers from the high-pressure cylinder, as is the engines of the "Gitana," making, of course, the same number of strokes per minute as as the engines. The condensing water is forced through the condenser by a centrifugal pump, with an auxiliary engine, assisted by a special form of grating, which, by means of gradually expanding openings, converts the external relative velocity of the wa-

ter into pressure. The thrust-block is secured to the bedplate of the engine by two stays, one attached to each side, and level with the center of the shaft; thus preventing any tendency to throw undue thrust on the lower half. The slide-valves of the engines are balanced by being placed under bridges, which are made with recesses corresponding to the ports in the cylinders, as used by Mr. Wilson, of Patricroft. In order to obviate the difficulty caused by the varying deflection under varying pressures, each bridge is in section like a bowstring girder, the bow not being attached, however, to the string except at the ends; and, by connecting the intermediate space with the exhaust, the flat surface is little distorted by pressure, and does not partake of any deflection affecting the bow. This construction of Mr. Wilson's valve is due to Mr. J. Donaldson, M. Inst. C.E., and appears to answer its purpose well.

The packing rings of the pistons are of Perkins metal, four in each piston, in separate grooves. They are found to work much more quietly than the single wide rings usually adopted in marine engines.

The fan engine is similar to the one employed in the "Gitana." Two feed pumps are worked by a cast-iron four-thread worm on the engine shaft, geared into a suitable wheel of phosphor-bronze secured to a steel shaft, having cranks at the ends, to each of which a feed pump is connected. The ratio of the gearing in the worm and wheel is as 4 to 15. The feed pumps are 4 inches in diameter, with a 3-inch stroke. The engine room also contains a bilge pump, which is worked from the feed pump shaft; and an air-compressing pump, with a separate engine, for charging torpedoes. A donkey pump is fitted in the stokehole, by which the boiler can be supplied when the main engines are at rest.

The propeller is constructed with three blades, and is placed forward of the rudder. It is four feet 6 inches in diameter, and has a pitch of 6 feet.

The boiler is of the locomotive type, and has a total heating surface of 620 square feet, of which 56 square feet are contributed by the fire-box surface. The area of the fire grate is 18.4 square feet.

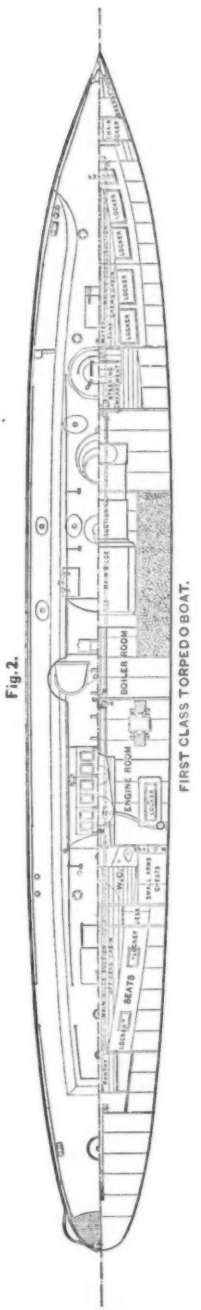


Fig. 2.

The outer shell is 4 feet 5 inches in diameter, and 12 feet 6 inches long. It contains two hundred and five tubes 6 feet long, measured over the tube plates, and $1\frac{3}{4}$ inch in external diameter. The working pressure is ono hundred and twenty lbs.

An important feature in the boiler is the fire box. In the boilers of the smaller type of torpedo boats, the roofs of the fire boxes are stayed with ordinary longitudinal beams; but in the boilers of the larger type, where the fire grate amounts to more than 18 square feet in area, the roof of the fire box is stayed directly to the outer shell of the boiler, made flat for a width equal to that of the top of the fire box, to which it is connected by vertical stays. By this mode of construction, there is the advantage of adding slightly to the steam room, but this alone scarcely balances the extra weight of material used in construction. It is, however, more convenient for staying than the radial system when the outer shell is cylindrical over the fire box; and there is more elasticity to take up any unequal expansion between the fire box and the shell. The shells of the boilers are mostly of steel. In the earlier boats, the fire boxes were of copper; but in the boats built for the English Admiralty, the fire box has been constructed of iron, as the boilers are liable to be fed with salt water. At the same time, iron fire boxes possess greater strength than those of copper.

In order to extinguish the fire, in cases when it must be extinguished and cannot be drawn, a rose with an ejector is fitted, in constant communication with the sea, by admitting steam to which the fire may be extinguished in a very short time.

Provision is also made, by self-closing ash-pit doors, for preventing the return of vapor to the stokehole. A passage to the deck is also provided to facilitate the escape of the steam discharged in the event of a tube giving way.

Experiments were made at Portsmouth to ascertain the performance of the boilers of the first-class torpedo boats, the results of which are given in the annexed Table, I.

TABLE I.—BOILER TRIALS, FIRST-CLASS TORPEDO-BOAT NO. 3.

Air pressure in stokehole.....inches	2	3	4	6
" " ash-pit..... "	1.47	2.29	3.26	5.25
" " furnace..... "	1.35	1.87	3.0	4.33
Temperature, feed-water.....Fahr.	53.5	57	54	56
" funnel..... "	1,073	1,192	1,260	1,444
Steam pressure (above atmosphere).....lbs	117	117	115	115
Coal consumed per hour..... "	925	1,177	1,472	1,815
" " " per square foot of fire-grate..... "	49	62	78	96
Water evaporated per hour..... "	6,530	7,770	9,320	10,840
" " per lb. of coal..... "	7.06	6.6	6.33	5.97
Evaporation per lb. of coal reduced to equivalent at 212° F. from 100°	7.61	7.08	6.81	6.41
Evaporation per hour per square foot of heating surface.....	10.8	12.9	15.5	18.0
Coal used, Nixon's navigation. Ashes, 9 per cent.	H. M.	H. M.	H. M.	H. M.
Duration of experiment.....	2 0	2 7	1 39	1 27

The influence of the pressure of air employed on the rate of evaporation and of combustion, and on the temperature of the gases leaving the boiler, is clearly manifested. The measurements of the pressure in the stokehole, ash pit, and fire box, show that of the initial pressure, the resistance of the tubes accounts for about seven-tenths of the whole, the resistance of the fire and fire bars being only about one-tenth. The loss on entering the ash pit appears too large, and the indicated deficiency of pressure under the bars is perhaps partly due to the comparatively high velocity of the air at this part of its transit. The pressure in the funnel, as measured, was sensibly equal to atmospheric pressure. The evaporative duty of the fuel in this boiler varies from 6.4 lbs. of water, evaporated with 6 inches of air pressure, to 7.6 lbs. with 2 inches, when reduced to the equivalent for feed water of 100° evaporated at 212°; and as the consumption of fuel per square foot of fire grate was 49 lbs. per hour with only 2 inches of air pressure, the results would have been of greater interest had lower press

ure of air also been tried. The boiler, even at half-engine power, is worked too hard to give high duty; but to obtain the highest speed, when coal has only to be carried for a short distance, it is necessary to work the boiler above its economical rate of evaporation.

If it were intended to carry a supply of coal for great distances, no doubt more heating surface should be provided for a given power. The boiler made by Messrs. Clayton and Shuttleworth, and tried at Cardiff, evaporated (equivalent from and at 212° Fahrenheit) 11.8 lbs. of water per lb. of fuel, and gave the highest duty at that trial; but the evaporation per square foot of heating surface per hour was only 2.2 lbs., whereas the boiler tried at Portsmouth evaporated 18.0 lbs. (equivalent at 212°) per square foot of surface per hour, being fully eight times as much.

Amidships, the deck is raised, so as to give room to work the fire and the engines, the depth of the vessel otherwise not being sufficient for this purpose. On either side of this raised deck, the torpedo davits are fixed, and the torpedoes are so carried as to hang within the width of the boat, for security. Air for the fire is taken in at a cowl, situated just astern of the after bulkhead of the engine room, against which may be seen the disc of the blowing fan.

The deck forward is much rounded, so that any water that may come on board can run off with facility. The stepped section amidships partially gives the same result. It affords much better foothold than the rounded surface, which is very necessary for the men at this place.

The stern frame extends considerably below the rest of the vessel, and carries the rudder abaft the screw. This frame is a Bessemer-steel forging, carefully shaped to a long elliptical outline in horizontal section, parallel, of course, to the direction of its intended motion through the water, in order to reduce, as far as possible, its resistance. The boat is fitted with a bilge suction-pipe to each of the principal compartments. Indexes on deck show what communicating valves are open. In the section, Plate 4, Fig. 3, it will be observed that the boiler is placed lower at the forward end than at the fire-box end. The boilers, however, assume a horizontal position when the boats are at full speed, in consequence of the change of trim. This change amounts to about 3 feet 10 inches in 100 feet, according to the results of experiments on the "Miranda." By Mr. Froude's model of the "Lightning," at a speed corresponding to 19½ knots, it was shown that the vessel inclined 3 feet 5 inches in the same length, 100 feet; an inclination which does not differ much from that of the "Miranda."

SECOND-CLASS TORPEDO-BOAT.

This boat is 60 feet in length, with a beam of 7½ feet. The draught is 12½ inches forward, and 3 feet 4 inches aft. The displacement is 10.6 tons.

The engines are compound, surface-condensing, and work up to about 112 indicated HP. The cylinders are 7 inches and 11 inches respectively in diameter, with a stoke of 8 inches. The air pump, operated by levers, is 7 inches in diameter, with a stroke of 2 inches. Two feed pumps are worked by worm and wheel, as described for the first-class boats.

The circulation of the water in the condenser is effected entirely by an apparatus, by which the external motion of the water when the boat is moving is utilized. An ejector is also fitted for removing air from the water space of the condenser, which is partly above the load water line. By this apparatus sufficient circulation can be maintained, when the boat is at rest, to condense any steam that may be required to be condensed in order to prevent its escaping into the air.

A small engine is used for blowing the fires, the same as described for the first-class boats; but it is made to drive two pumps, which can be connected when required.

The boiler is of the locomotive type, and has a total heating surface of 198 square feet, of which 22 square feet are supplied by the fire-box surface. The area of the fire grate is 6.3 square feet. The outer shell is 3 feet 1 inch in diameter, 7 feet 7 inches in length, and contains one hundred and twelve solid-drawn brass tubes, 48½ inches long, and 1½ inch in external diameter. The working pressure is 120 lbs.

Fig. 3 represents the sheer draught of

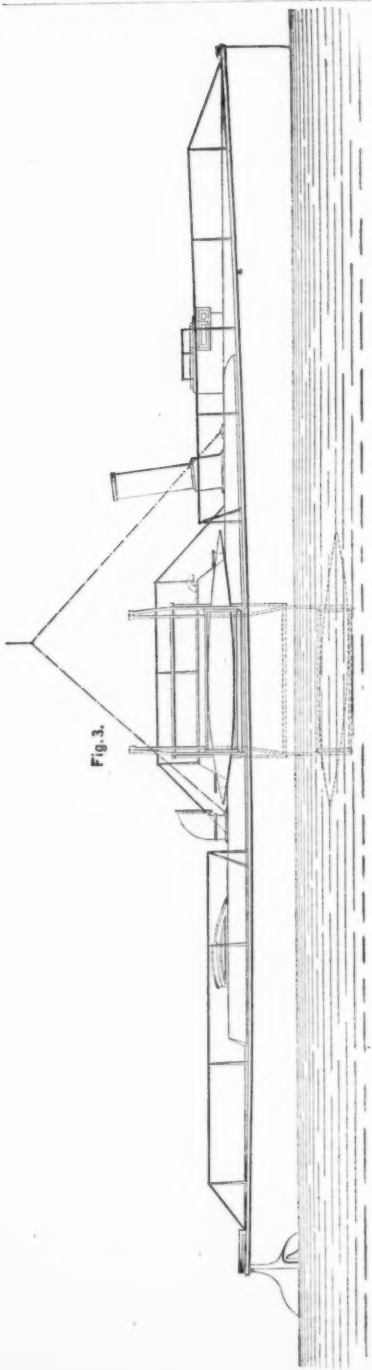


Fig. 3.

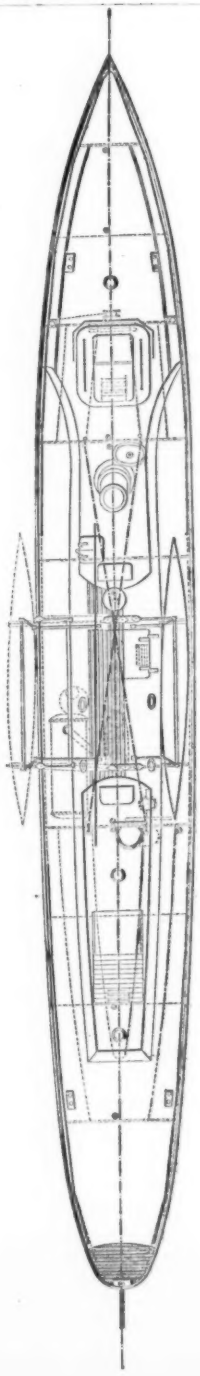


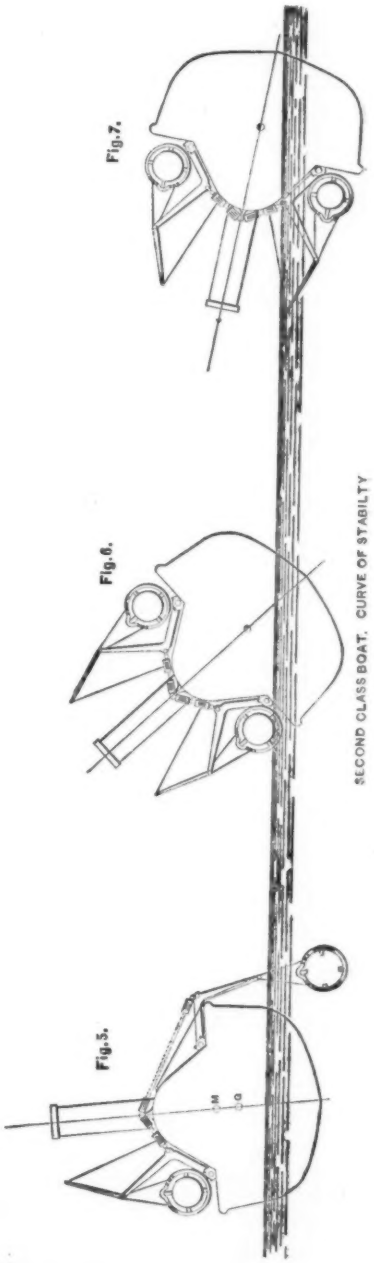
Fig. 4.

the boat, with a "Whitehead" torpedo in davits, as carried. The boat is also seen in Fig. 4. It is divided into six watertight compartments, and is subdivided up to a level considerably above the water line, by half bulkheads. The vessel is steered from forward. The conning shield over the steering wheel is of 4-inch steel plates on the forward side.

Figs. 5, 6 and 7 represent the second-class torpedo-boat in cross section, and are intended to illustrate its stability. Fig. 5 shows the inclination due to the absence of one torpedo when the unbalanced weight of the other inclines the boat to about $5\frac{1}{4}°$. Fig. 6 shows the boat inclined until the righting force has become a maximum, which happens at about 42.° Fig. 7 gives a section of the same boat heeled over until the stability is just vanishing, when the angle is about 79°. This angle comprises a large range of stability, which is favorable to the safety of the boat.

The boiler and engines being, in the second-class torpedo-boats, contained in one compartment, there is some advantage in point of simplicity over the larger type. But this disposition involves so large a compartment as would endanger the boat if it were filled with water. It has therefore been decided to separate the engine from the boiler by a bulkhead, in the new boats of this class now being built. Any one compartment in these boats may become flooded, and yet an ample degree of buoyancy would remain.

These boats are designed to be carried on board ship, and they require to be slung overboard complete and ready for use. This condition involves their being subjected to considerable stresses. To illustrate the effect of their being thus suspended the data for the curves, Figs. 8 and 9, have been calculated. In these diagrams, the weight of the vessel is represented in amount and distribution by the area contained between the base line X Y, which also represents the length of the vessel, and the curve lines WWW. The points of support, when suspended, correspond to the points P_1 P_1 in the diagram; and for simplicity the vertical components only of the forces acting through these points in this case are at first taken. The bending moment at any section of the hull is



represented by the distance of the line M M M from the base X Y, the shearing forces being, in the same way, represented by the distance of the line S S S from the same base line. When the oblique forces are considered, and the

SECOND CLASS BOAT.
CURVES OF SHEARING FORCES AND BENDING MOMENTS WHEN SUSPENDED.

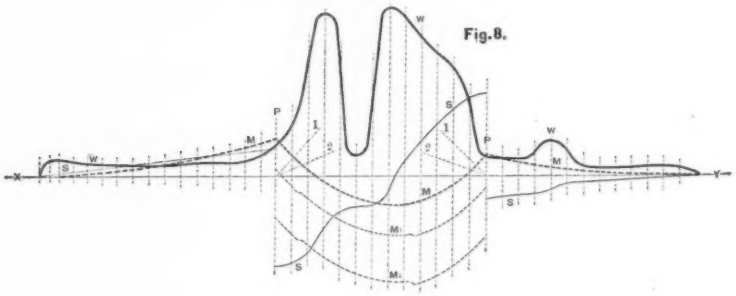


Fig. 8.

slings take the lines 1, 1, or 2, 2, the bending moments for sections between P and P, will be increased as shown by the line M_1 or the line M_2.

The curves M and S S, in the diagram, Fig. 9, represent the bending moments and shearing forces to which the hull is subjected when floating in still

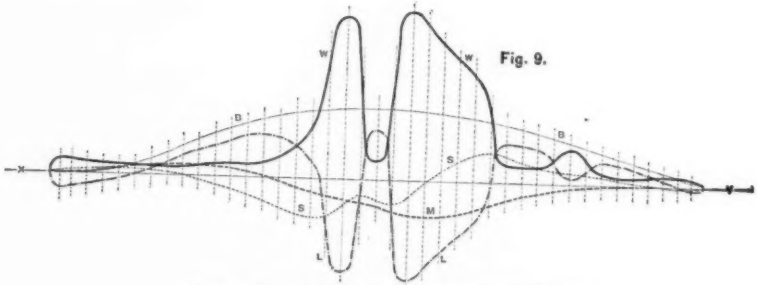


Fig. 9.

CURVES OF SHEARING FORCES AND BENDING MOMENTS WHEN AFLOAT

water, where the area between the line B B and the base line represents the supporting force, or displacement. The line L L represents the curve of loads, or difference between the curve of weight W W and the curve of displacement B B at any point. The ordinates for the line B B and M M being drawn to the same scale, it is evident that the greatest stress to which the boat is subjected on being lifted, is only a small part of its ultimate power of resistance; the maximum stress on the material being about 7,000 lbs., or 3.14 tons per square inch.

CONCLUSION.

A few examples of the weight of hulls in percentage of displacement, taken principally from sea-going vessels, with the co-efficient of fineness of form, are given in Table II. (p. 365.) By comparing the hulls built by the author's firm it will be seen that the weight has not been unduly reduced; for although they are lighter, their relatively short lengths afford great advantage for relative strength.

A selection of practical instances is given in Table III. (p. 366), to show by contrast the progress that has been made in concentrating power in a small compass, and at the same time reducing the weight of the machinery and of the boilers. The quantities in the seventh column of the Table—cylinder capacity per

TABLE II.—PROPORTIONATE WEIGHT OF HULLS.

Name of vessel.	Percentage of displacement		Co-effici'nt of fineness.
	Weight of hull.	Weight carried.	Immersed volume. Midship section × length.
	Perct.	Perct.	
Circular ironclads....	20 to 22	78 to 80	0.780
Iron merchant ships.	30 " 35	65 " 70	—
H.M.S. Bellerophon..	49	51	0.698
H.M.S. Inconstant...	51	49	0.614
H.M.S. Devastation..	31	69	0.766
H.M.S. Iris.....	32	68	0.548
H.M.S. Inflexible....	34	66	0.721
Lightn'g torpedo boat	33	67	0.601
1st-class " "	33	67	0.583
" with ram bow.	33	67	0.552
2d-class torpedo boat.	30	75	0.591
Miranda (yacht).....	35	65	0.561
Gitana (yacht).....	33	67	0.662

indicated HP.—are deduced by dividing half the volume swept by the pistons in one revolution by the indicated HP. They are approximate measures of performance relatively to the bulk and weight of the engine, irrespective of the boilers.

Table IV. (p. 366) contains some additional comparative results of the performance of large steam vessels of the navy, and the yachts and torpedo boats before described.

On comparing the contents of the Tables III. and IV., it appears that the "Gitana" presents the lightest machinery in proportion to indicated HP., weighing only 43½ lbs. per indicated HP., or a little over one-eighth of the machinery of the Holyhead mail boats, and only one-fourteenth of that of the American paddle river boats, the "City of Boston" and the "City of New York." Correspondingly, the volume of cylinder per indicated HP. of the "Gitana" is but one-fourteenth of that of the Holyhead boats, and only one twenty-third of that of the American boats. In this respect, the "Miranda" excels even the "Gitana," having only 6.3 cubic inches of cylinder capacity per indicated HP., or little over one-third of that of the "Gitana."

The consumption of fuel in the torpedo boats has been approximately measured, and is about 3.9 lbs. per indicated HP. for the first-class boats when developing 340 indicated HP., and 3.5 lbs. for the second-class boats at 112 indicated HP.

From the last column of Table I. it appears that from 1 square foot of fire grate 28.4 indicated HP. were developed in the "Gitana"; whilst, in the last column but one, 1 indicated HP. was developed for 1.33 square foot of heating surface, in the first-class torpedo boats.

With regard to the relative consumption of fuel for each indicated HP., it is apparent that the lighter machinery consumes more than the heavier machinery. But the excess of consumption is due, not to comparative lightness, but to the fact that the boilers are proportionately overworked, as is clearly proved by the high rates of consumption of fuel per square foot of fire grate. The ratio of expansion used in the torpedo boat engines seems, perhaps, less than desirable, but the gain from expanding more than five times with the pressure used, would be very limited, whilst the weight of engines would be materially increased.

In comparing, in Table IV., the performance of small vessels with large ones, the common formula $\frac{V^3 D^{\frac{3}{2}}}{I.H.P.} = C$, is convenient and suitable; for if similarly formed vessels of different dimensions are propelled at what Mr. Froude has called "corresponding speeds" (speeds proportioned to the square root of their linear dimensions), the power required varies in such a manner as to give a constant value to this fraction, if the effect of the different proportion of surface friction to the whole resistance may be neglected in the comparison; and, as the increased proportion of surface friction in small vessels has the effect of reducing the value of the constant C, this formula cannot be supposed to favor the particular kind of craft under discussion. The high value obtained by No. 10 torpedo boat, Table IV., is worthy of remark; but it should be noted that this boat had the advantage over others of its class, that no bilge keels were fitted, and the stern frame did not extend below the propeller boss.

TABLE III.—RELATIVE PERFORMANCE AND WEIGHT OF STEAM VESSELS, AND LOCOMOTIVES.

Date.	Name of vessel.	Fuel per square foot of fire grate per hour.	Boiler pressure.	Revolutions per minute.	Speed of piston in feet per minute.	Indicated HP.	Cubic inches of cylinder per indicated HP.	Weight of propelling machinery, including boilers with water.		Heating surface per indicated HP.	Indicated HP. per foot of fire grate.
								Per Indicated HP.	Per cub. inch of cylinder.		
		Lbs.	Lbs.					Lbs.	Lbs.		
1855	City of Boston and City of New York.....	—	35	20.0	480	1800	402.0	606.0	1.50	—	—
1857	Persia.....	—	25	15.0	360	4950	457.0	498.0	1.08	—	—
1861	Holyhead mail boats.	—	—	22.0	286	4751	248.0	318.0	1.34	—	—
1878	H.M.S. Inflexible....	21.0	61	73.2	585	8483	185.0	420.0	2 26	—	—
1829	Rocket, locomotive..	36.0	—	143.0	393	22	73.0	286.0	3.98	—	—
	Modern locomotive..	80.0	120	240.0	880	—	—	—	9.80	—	—
1872	Miranda (yacht).	—	120	600.0	800	64	6.3	62.8	10.00	1.84	16.2
1876	Gitana (yacht).....	138.0	120	320.0	850	460	17.3	43.5	2.52	1.53	28.4
1877	First-class torpedo boats..... (lightning class)	100.0	120	440.0	880	455	12.0	57.7	4.80	1.33	23.4
1879	Second-class tor-	60.0	120	600.0	800	108	9.9	81.6	8.26	1.82	16.6
1880	pedo boats.....	78.5	130	650.0	866	150	9.1	66.5	7.27	1.66	23.1

TABLE IV.—RELATIVE DISPLACEMENT AND PERFORMANCE OF STEAM VESSELS.

Name of vessel.	Date.	Length on W.L.	Displacement.	Indicated HP.	Speed in knots per hour.	$\frac{V^3 D^{\frac{2}{3}}}{I.HP.}$	Blast in ins. of water.	Revolutions per minute.	Steam pressure in boiler.	Receiver.	Vacuum in condenser.	Fuel per indicated HP. about.
		ft. in.	tons.	I. HP.	knots.	constant	ins.	turns.	lbs.	lbs.	ins.	lbs.
Miranda.....	1872	45 6	3.7	64	16.20	160.0	—	600.0	120.0	—	—	—
Gitana.....	1876	86 0	29.0	460	20.75	183.0	4 to 6	320.0	120.0	—	—	—
1st-class torpedo boat No. 1	1877	81 0	28.7	400	18.55	150.0	—	350.0	120.0	35.0	25.25	—
" " " 6.	1879	83 9	32.43	425	20.00	191.5	5	420.0	120.0	36.0	25.0	3.92*
" " " 10.	1880	88 3	29.73	460	22.01	223.0	5	438.0	123.0	36 0	24.5	—
" " " 10.	1880	88 3	32.5	469	21.756	224 0	5½	443.0	133.8	40.5	23.8	—
2d-class torpedo boat.	1879	58 4	10.6	108	16.51	184 0	3½	600.0	120.0	38.0	24.5	3.51
" "	1880	60 10	10 9	150	17.645	180.0	3	653.0	131.0	41.3	22.4	—
H.M.S. Inconstant..	1869	339 0	5,328.0	7,361	16.513	186.0	—	74.5	30.4	—	25.3	3.25
H.M.S. Inflexible...	1878	324 0	9,515.0	8,483	14.74	169.0	—	73.26	61.0	—	26.5	2.06
H.M.S. Iris.....	1878	301 6	3,290.0	7,556	18.573	189.0	—	97.2	65.0	—	2.7	2.75

* The consumption 3.92 lbs. took place with a first-class torpedo boat, when indicating 340 indicated HP.
† The consumption 3.51 lbs. took place with a second-class torpedo boat, when indicating 112 indicated HP.

DISCUSSION. (ABSTRACT.)

Mr. THORNYCROFT asked permission to add a few words with reference to the vibration of the boats at high speed. He did not mean to say it was necessary that there should be vibration at high speed; but each boat had a particular vibration due to the strength and weight of its structure, and if the engines were run at the same number of revolutions as the boat would make beats, there would certainly be a considerable vibration of the hull. It was generally practicable to

run engines at a higher speed than the natural period of the boat's vibrations. In the case of one of the Government torpedo boats, the "Lightning," it had recently been ascertained that the boat vibrated considerably at about three hundred and sixty revolutions per minute, and that it continued through some little range. It was found desirable to alter the propeller, so as not to run at full speed, at that particular speed of the engine.

Mr. A. F. YARROW inquired whether the author had any data touching the consumption of fuel by his vessels for long distances, as that was becoming a matter of considerable importance. He might mention that in boats 100 feet in length, built by his firm, having a displacement of about 40 tons, 1 ton of coal would last for a run of 100 miles at a 10-knot speed.

As to the pitch and size of propellers, he had found that in very fast boats a propeller giving anything less than 12 or more than 27 per cent. slip was bad. In propellers of large diameter there was, at very low speeds, a negative slip amounting to 1 per cent., and in some cases 1½ per cent. He believed there could be no possible mistake about this, as it had been confirmed by repeated experiments. He found that if a screw gave a negative slip at a low speed it was a bad propeller for all speeds. In well-proportioned screws the slip increased with the speed up to 18 knots per hour; above that it slightly diminished.

It was the practice of this firm to use two-bladed screws, as they believed there was a slight gain over three-bladed ones. It had often been said that, probably from using a two-bladed screw, their boats vibrated more than they otherwise would do, but this he believed was not the case. He thought if a two-bladed screw was well immersed and perfectly balanced, there was really no vibration whatever due to it. The vibration was mainly caused by the unbalanced vertical movements of the engine. This had been ascertained by removing the propeller from one of their boats, and then working the engines. The vibration was precisely the same, in degree and in kind, as if the boat was traveling. Also, in a torpedo boat 86 feet in length, when the engines were making two hundred, four hundred, six hundred or eight hundred revolutions per minute, the vibration was excessive, but at intermediate speeds of three hundred, five hundred and seven hundred, the vibration ceased altogether, showing that there were speeds at which these boats must not be allowed to run for any length of time, since serious vibration meant excessive wear and tear.

He thought any discussion on this subject would be incomplete unless reference was made to the Herreshoff torpedo boat, as, although it proved a failure, it still combined a great number of novelties, and was the most ingenious and interesting vessel of its class that had ever been brought out, and did infinite credit to its designers.

There was one point to which he would specially allude, viz., the position of the propeller, which was under the bottom of the boat. This position had its advantages and disadvantages, and his firm took an early opportunity of testing the value of it in one of their large boats. They selected for the purpose a boat of the usual size and power to make a fair comparison. They found, contrary to expectation, that instead of obtaining an increased speed, due to the propeller working in more solid water, there was a loss of speed. In fact, it was ascertained by comparing it with other boats having the propeller placed in the usual position, that there was a waste of 80 HP. out of 450 HP.; that was to say, with the same power, the loss in speed was about 1½ knot per hour. He believed this might be due to the propeller, being under the bottom, causing a stream of water to flow with considerable velocity in the opposite direction to that in which the vessel was traveling, inasmuch as the boat was passing through water partly at rest, and partly having motion in the opposite direction, causing increased skin friction.

It had become a question in what way machine guns affected torpedo boats. He estimated that a weight of 10 tons, distributed over the deck and sides of a torpedo boat 100 feet long, would give ample protection against the guns at present in use; that was at a distance suitable for firing the Whitehead torpedo. As experiment demonstrated that, in a 100-feet boat having 40 tons displacement, for every ton additional carried there was a reduction in speed of nearly

¼ knot; it followed that the extra 10 tons weight represented a loss of speed amounting to 2½ knots; and it rested with naval authorities to determine whether the fraction of speed or the protection was the more desirable.

There was only one small point in which he differed from the author, who stated that the most favorable position for the propeller at high speeds was astern of the rudder. If, at the same time as placing the rudder aft of the screw, the propeller itself was bodily moved nearer to the stern of the boat, then he was prepared to admit that there would be a reduced efficiency, but this reduced efficiency would be due to the altered relative position between the propeller and the stern, and not really to the rudder. Not only did he consider there was no loss by the rudder being placed aft of the screw, but he was of opinion that there was a positive although but a small gain. The reason for believing that the rudder being aft of the screw added to the efficiency, was because it had a tendency to check the rotary motion of the water.

Some time since his firm tried some experiments with a propeller or turbine, similar to what the Hon. R. C. Parsons, Assoc. M. Inst. C.E., and others had advocated, and which consisted of a ring provided with blades formed as screw blades. This propeller was placed in the usual position at the end of the shaft. Aft and close to this, there was another fixed ring, with guide blades in it curved in such a manner as to take up and utilize, for the propulsion of the vessel, the rotary motion imparted to the water. They had tried some experiments on a boat with this arrangement in three forms:—in the form just described; also by substituting straight guide blades for the curved ones; and also without guide blades. As might have been expected, without guide blades the efficiency was very inferior; but whether the guide blades were straight or curved was a matter of little importance, showing that guide blades (although straight) added to the efficiency of the propeller. From these experiments, he contended that the same thing held good, but to a much smaller extent, with an ordinary screw, in which case the rudder acted the part of a guide blade.

Again, in confirmation of this argument, he might mention that his firm built two boats, one with the rudder aft of the propeller, and one with the rudder forward of the propeller, but the relative positions of the propeller and of the stern were the same. The result was that the boat having the rudder outside the propeller, gave a trifle higher efficiency for the same HP. It must be borne in mind that, in dealing with this question, the rudder was assumed to be made so as to offer the least possible resistance; and his firm always made their rudders out of a solid steel forging exceedingly fine at the forward and after edges.

The author had stated that in the boats supplied by him to the English government he was in the habit of using iron for the fire boxes, and that they possessed greater strength than if made of copper. It was the usual practice of his firm to use copper and not iron where a very high rate of combustion was required, because they thought it a more suitable and reliable material when subjected to intense heat and rapid changes of temperature; their impression being that iron for such a purpose was somewhat treacherous. It would be of great interest to ascertain the comparative merits of copper fire boxes and iron fire boxes, also of iron tubes, brass tubes, or iron tubes with copper ends, as it appeared the choice lay between these three. Concerning this question he believed his firm was not alone in having had considerable trouble in keeping the tubes in the fire box tube-plate tight. It was one of the greatest difficulties they had to contend with. About three years ago, when they were greatly troubled in this respect, their attention was drawn to the ovaling of the tube holes by Herr A. Waldfogel, chief engineer of the Austrian navy, and also by Mr. E. J. Cowling Welch. They at once set about trying some experiments to test exactly what was going on with the tube plate when the boiler was in steam. The first row of stays next the tube plate was removed from one boiler, and other stays substituted, fastened to the copper fire box as usual, and passing through stuffing boxes on the outside shell. There was a nut on the end of each stay bearing upon the gland of the stuffing box in case a tensile strain came upon it. When the boat was steaming and there was a fierce fire inside, all these

stays were relieved from tension, and in fact the stays had moved through the stuffing boxes to the extentof from $\frac{1}{16}$ inch to $\frac{1}{8}$ inch. It was exceedingly interesting to remark how suddenly, when the fan inside the stokehole was stopped and started, the stays moved in and out of the stuffing boxes, showing, in this class of boat, where the combustion was constantly varying, what unfavorable strains must come on the tube plate if the stays next the tube plate were rigid. In one case, the extension of a tube plate was $\frac{3}{8}$ inch in the first run. It was now their practice to fit the first complete row of stays in copper fire-box boilers, with stays arranged in such a way that they could expand and contract freely, as was done by some locomotive builders on the Continent. He might mention also that of late they had made a drop in the fire-box top of 4 or 5 inches, so that an area of at least three-fourths of the fire-box top was on a lower level than the portion next the tube plate. This allowed a little longitudinal movement, and at the same time gave a greater depth of water over the fire-box top, which in small sea-going vessels he believed to be desirable.

Mr. J. R. Ravenhill said, although Mr. Yarrow had given a most interesting account of his experience, he had stopped short in his explanation. There could be no doubt that the speeds attained by the boats of Messrs. Thornycroft and Messrs. Yarrow were very nearly alike. Mr. Yarrow had alluded to a difference in the form of the propeller, but he had not mentioned certain details of his arrangements differing from those shown in the engine exhibited by the author. Mr. Ravenhill would therefore venture to supplement what Mr. Yarrow had stated, so that the members might have before them the means by which such high speeds were attained. Messrs. Yarrow attached the main engines alone to the shafting. For working their air pumps and feed pumps, an auxiliary engine was employed, and by this means ran them at a much less speed than was adopted by Messrs. Thornycroft, whose practice had been to run them at a greater number of revolutions. There was barely a limit to the number of revolutions that might be run, the engines being put direct on to the shafting, and driving only the propeller. It was a movement in the right direction, because there was no doubt that, by piston speed, weight might be saved. The weight of the machinery in the torpedo boat was, as had been stated by both makers, a most important element. It might be that they could not do very much more than they had done with reference to the engine, because they made so many parts of steel. There was very little cast iron left for them to cut and pare on. In his opinion, there was a considerable advantage in having the air pumps distinct from the engines. They could be started with a vacuum at any time by taking care to have the smaller engines at work first. Any one who had been accustomed to see these quick-running engines well handled would fully understand the advantages to be obtained in that way. It was the boiler to which attention would have to be directed for the further saving of weight. The weight of the locomotive boiler was considerable—probably 30 per cent. of the whole. The water-tube boiler had hitherto not answered all expectations. Two or three different forms had been tried, but he believed that before long some form of water-tube boiler would be found essential. Engineers who were paying attention to that class of machinery could not do better than bestow great attention on that point, until the right kind of boiler for torpedo vessels was discovered. The author had, in Table III., alluded to the Holyhead boats, and there were one or two points in connection with the Table to which Mr. Ravenhill desired to call attention. The indicated HP. was clearly that of the "Leinster." The revolutions per minute were stated as twenty-two, but when the vessel was indicating the power quoted in the Table, the revolutions were 26½ per minute, which would give a speed of piston of 354½ feet per minute. The boiler pressure was 25 lbs., and the indicated HP. per foot of fire grate 16.7. The improvement shown was no doubt very marked, but he should have been glad if the author had supplemented his figures by stating what was the performance of some of the merchant steamers at the present time. A large vessel recently, when on trial, had a piston speed of over 800 feet per minute for a considerable time, and her ocean speed was to be 780 feet per minute.

Admiral Selwyn had been delighted to listen to the exposition which the author had given of some of the advantages that had accrued to the world by the study of principles of which he was the first exponent: how light and yet powerful engines should be made, how light and how handy vessels could be constructed, and how fast they could be driven; which to a naval man involved the whole question of success at sea. He had given a dissertation on the work accomplished, the result of long years of observation reduced to successful practice. Some of his conclusions might be open to question. Admiral Selwyn might demur to the first conclusion, that if better results than had been obtained were desired, it would be necessary to resort to larger boilers. He should be disposed to ask whether the fuel employed could not be changed, and whether it was necessary to provide larger boilers, which instead of giving 11 lbs. of evaporative duty under the plenum to which they were subjected of air-pressure and consequent oxygen blown in to promote combustion, gave an economy much less than desirable, and than what he had said had been found in the same boilers under their natural draught. That was the solution of the difficulty, but not in the most philosophical way. He should have desired to see some reference to the proportions between the strains and the margin of the load—to see how nearly a safe load on each part of an engine and a boiler had been attained, and whether a continuance of work under those loads could be relied on. He likewise wished to advert to the mode of propulsion by screws. His recollection extended back to the first screw known in the country, the Archimedean screw. It was not, however, absolutely the first, because that was exhibited more than two hundred years ago by a working shipwright, and he believed was still to be seen in Plymouth yard. No remarkable advance had been made in screws. A screw, as the author had well said, would give a very fair result, seven-tenths of the power applied to it, so long as no air came to it; but the instant a screw vessel was taken into the disturbed ocean, air was an inevitable accompaniment. The vessel would pitch in nine cases out of ten, and the screw as a propeller was then in the inefficient condition which the author had described, about 50 per cent. of the power being wasted. He thought it would be necessary to go a little further and contemplate a different condition of the screw altogether. With regard to the Herreshoff boiler, referred to in the paper, although it was doing wonders in the way of evaporation, as might be expected where a small quantity of water was subjected to a very high heat in a coil, it was not reliable unless distilled water was used. The Herreshoff coil was one of the oldest inventions on the subject, having been produced by the grandfather of a celebrated inventor in high pressures many years ago, but it was given up by him as not being an efficient instrument. Engineers ought not to be misled either by the Herreshoff boiler, or by the position of the screw. This position had been described as occasionally causing loss instead of gain. If the screw were put sufficiently deep down to run in the undisturbed water surrounding the vessel, then, like all other propelling instruments, it would give its best effect; but if the velocity of the vessel were increased, and the accompanying skin of water increased also in depth, there might be a loss instead of a gain. As in the case of all screws, in whatever position, it depended entirely upon the speed of the vessel, and the position of the screw relatively to that speed. No such instrument would succeed unless it was tried under all conditions. It would give a great effect when the speed of the vessel was not such as to carry the skin of the water round the vessel deeper than the upper part of the blades; it could give no effect at all, or a negative effect, the instant it was comprised in the current carried by the vessel which the late Mr. Froude had defined. Sir William Thomson had an objection to the Berthon log or speed measurer. Many persons had been charmed with the idea of having an instrument like a barometer in the cabin to measure the speed of the vessel. It was thought that if a tube were taken out of a vessel which showed the pressure on the bottom of it, in that way the measurement of speed could be obtained; but Sir William Thompson's experiments had shown that unless the tube were pro-

longed for each speed of the vessel below the skin of the vessel, the result would be worthless. It was necessary to have it in undisturbed water, which it was not possible to get under ordinary conditions. With regard to the question of engines, overhung as the cylinders were now in most of the compound engines adapted to torpedo boats, he could recognise the fact that it was sufficient to provide for vertical pressure in smooth water; but he denied the fact that if the vessel were to be considered subject to the ordinary motions at sea, it was safe with any large sized vessel to rely on such a provision for unison with working surfaces. If the cylinders were a considerable portion of the weight, the engines suported only vertically, and stayed to a yielding skin, a motion of two inches from side to side, such as he had sometimes witnessed, would throw strains which he was certain no constructor had ever calculated, on every part of the engine. He was not surprised, under those circumstances, that many parts calculated according to the usual law of strains had been unable to bear the stresses thrown upon them. Reference had been made to the compound engines of a United States revenue steamer, in which the cylinders were thoroughly steam-jacketed, with the steam at 82 lbs. per square inch initial pressure. What was meant by being thoroughly steam-jacketed? It meant a heat and a pressure superior to that at which it was intended to use the steam inside the cylinders; and 82 lbs. pressure did not involve a very high degree of heat kept up. The losses by external radiation might well be equal to the loss by radiation from 82 lbs. steam; but dealing with much higher pressures and higher temperatures, enormous values might be got out of steam-jacketing, and if it was ignored it was impossible to conduct the expansion which ought to be due to high pressures, and which gave them their chief value with any good result. During some recent experiments in America, the steam-jackets were considered useless, and had been shut off, and the engineers were puzzled to find that there was much condensation of water in the cylinders, because the jackets had been carefully cut out, and the steam was left to go in at high pressure and to on dense in the cylinders to form water, tasking the whole of the work to get rid of the water, so that the economy fell much below what it ought to have been. Reference had been made to Perkins metal. He was interested merely in a scientific way, in knowing whether Perkins metal succeeded in preventing all scoring of cylinders at high temperatures and at high speeds of the piston. If it did, he thought the author would acknowledge that it was of no use to compare it with any other metal or any other rings. If, in the absence of lubrication, which had always been a difficulty, the Perkins metal showed an absence of scoring on the cylinders at the highest temperatures of steam, and the highest speeds of the piston, progress would be much faster than would otherwise be possible. It was not sufficient to consider the question that they worked much more quietly than single wide rings; the question was whether wide rings would work at all under those conditions? That was the interesting point to engineers. With regard to the water evaporated per lb. of fuel, he had long been an advocate of condensed fuel, by which an advantage could be gained that never would be secured by forced combustion. If combustion were forced, pouring in oxygen and nitrogen, all of which nitrogen must be heated up, and all of which heated gas was lost, doing no good whatever, so favorable an effect would never be got as could be obtained with the condensed fuel which could evaporate a large quantity of water without undue draught. Engineers might do away with the chimney draught, and not only be without a plenum in the stoke-hole, but not even have a vacuum in the funnel, or anything approaching it. There could thus be obtained an evaporation of 60 lbs. of water by a consumption of 1 lb. of fuel, plus 1 lb. of steam. If the chemical laws of combustion under which it was done were understood, it could be done again and again, as he had seen it done with a common Cornish boiler. There was one point which had especially struck him in connection with the paper. If the author and Mr. Yarrow could build boats which had an angle of vanishing stability of 79°, it was surely possible, with ironclads, by resorting to the same means, to obtain a much greater vanishing angle of stability than 45°. That was of the ut-

most importance to the navy of England. Ironclads were being built which did not command the confidence of those who sailed in them. It was a fashion to say that everything was done for the best, and that it was the best that could be done; but that, he felt sure, was not a principle that would commend itself to an assembly of engineers. Nothing was done while anything remained to be done, and so long as there was a possibility of increasing the stability of vessels, so long that increase should be sought. It was to be gained by a change of form, by amending the tonnage laws which at present limited the forms of merchant ships, by improving the shape above water without much affecting the midship section or the frictional surface, and therefore but slightly the speed of the vessel. If constructors would in many things follow the lead which the author had given, they would be able to make improvements, and naval architects of the highest class would gain very greatly, and obtain a title far beyond that which any Institution could give them to the confidence of their fellow countrymen.

Mr. James Wright, C.B., Engineer-in-Chief of the Navy, observed that in the remarks he had to make there would be little that was new, but he thought it only right to say a few words in reference to the experience of the Admiralty of the machinery supplied by the author of the paper. As to the engines, which had been severely tried, they had answered in every respect, and there had been no mishap of any kind—indeed there had not been even a case of hot bearings on the trials, a common thing in the trial of marine engines in the present day. When he stated that engines like those exhibited had been run for three hours continuously at over six hundred revolutions per minute, and for shorter periods six hundred and fifty, he thought that was saying a great deal. Indeed it was only fair to the author to say that, as far as the engines were concerned in the boats supplied by him to the Admiralty, they were as nearly as possible perfect for the purpose for which they had been designed. With regard to the boilers, he could not give quite the same unqualified testimony. They had done very well on the whole, but there had been some trouble with leaky tubes. The first boilers has brass tubes, and they leaked very much; then iron tubes were tried, but they leaked too. That was really the only structural defect encountered; the experience of locomotive engineers would no doubt help to overcome the difficulty. The other matter was that of the boilers priming. The author had mentioned that boilers of the locomotive type in torpedo boats should have larger steam room than ordinary locomotive boilers. He thought the author would have to go farther, and give more space between the tubes—in fact to make the boilers altogether rather more roomy. They were of course at a disadvantage compared with the ordinary locomotive boiler, because it was not always possible to get pure fresh water; the water had to be evaporated and sent through the engines over and over again; and although precautions were taken to keep out the oil as much as possible, there was no doubt that after a time the water became greasy, and that seemed to set up priming. That, however, could only be regarded as an occasional difficulty which would, no doubt, be removed in time. In other respects the boilers had been satisfactory. In Table III. the author had taken the "Inflexible's" engines as a type for comparison with the torpedo boat engines, and he had given the weight at 420 lbs. per indicated HP. The 420 lbs. had been taken upon the original weight when the ship was designed seven years ago; as completed, the actual weight was only 360 lbs., and the HP. so obtained was without any artificial blast, simply by the natural draught of the boilers. He merely mentioned the circumstance to show that modern marine engines stood rather better in relation to the examples of other engines given than the Table would indicate. To confirm what he had stated, he might mention that the weight of the "Nelson's" machinery was 360 lbs. per indicated HP., and that of the "Iris" only 320 lbs. Those weights had been taken upon trials with the natural draught; if the draught had been forced to a moderate extent, as it usually was in such trials, by the steam blast, no doubt the weight would have been but a little over 300 lbs. Of course, in any such system of machinery as that described, the ques-

tion of forced combustion was an all-important one, and no doubt the author had been quite right in adopting the best method. Some persons had objected to the method on the ground that it would have a bad moral effect on the stokers. It was thought that men would not readily be got to work the fires when shut up in a closed stoke hole without ready means of escape. He was glad to say that no such difficulty had as yet been experienced, and he did not think that it was likely to be. There was really no danger incurred. In all cases appliances were provided (first introduced, he believed, by Mr. Yarrow) for preventing any injury to the stokers by the bursting of a tube; and the author had advised another arrangement for the same purpose. In the very improbable case of a boiler explosion, he did not think it would be of much matter to the stokers whether the stoke hole was closed or not. With a view, however, of seeing whether any method of forced combustion approximating in efficiency to the one with the stoke hole under pressure could be obtained, so as to work with an open stoke hole, a number of experiments had lately been made in the dock yards, some with steam jets and some with blowing the air into the funnel. Forced combustion by the steam jet on the old system was very wasteful. Usually, in trials of ordinary marine engines, there could be got with the steam jet in the funnel an increased combustion of coal from 40 to 50 per cent. over what was obtained with the natural draught; but it was very wasteful, the increase in power not exceeding 15 per cent. over what was obtained with the natural draught. Of course, the steam jet could not be used for torpedo boats, as it would lead to the waste of fresh water in them. Trials were made in No. 3 torpedo boats (of which the author had given the evaporative results), using the same fan, but blowing air into the chimney. The fan was driven so hard as to give a pressure equal to 12 inches of water per square inch and upwards. Nozzles of different sizes were tried, from 2 inches up to 5 inches in diameter, such as the blast nozzles of locomotive engines; a slit ring was also tried, but the results were disappointing. In fact, the best result which was with a nozzle 3½ inches in diameter, was no better than what was obtained in the ordinary boiler with the natural draught; and it was not one-half what was obtained with two inches of air pressure in a closed stoke hole with the same boiler. The consequence was that he thought the idea must be given up of using any other means than the closed stoke hole. It was not a new thing; he believed it had been employed a long time in America, where dull-burning anthracite coal required a great deal of forcing; it was also gradually being introduced into France and in various parts of this country, for large ships. Altogether, it appeared to be the best system that could be adopted. About three years ago, observing the success that the author and Mr. Yarrow had obtained, the Admiralty had ordered from Messrs. Humphreys of Deptford a set of machinery on this system for the torpedo ram, "Polyphemus." The engines were expected to develop 5,500 indicated HP. Although ordered three years ago, the progress in building the ship had been very slow, and on that account they would probably not be tried for three or four months. The power was expected to be developed with a piston speed of 780 feet per minute—a very considerable advance on the ordinary speed at which marine engines were worked. The boilers would be ten in number, larger than any of those which the author had used for his first-class boats, and would be divided into four stoke holes. It was hoped they would not require an air pressure of more than two or three inches of water. The cylinders were much larger in capacity for the power than those of torpedo boat engines, and in other respects the engines had not been reduced in weight to such an extent as the torpedo boat engines; but the saving in total weight was considerable. It was expected that the weight per indicated HP., instead of being 360 lbs., would only be 180 lbs. The saving in actual weight would be about 320 tons, or over 40 per cent of the weight of the compound marine engines with boilers of the ordinary kind, like those of the "Iris." He thought the system would be applicable to fleet passenger steamers making short passages, where a large coal consumption was a matter of little importance, considering the short time they were under way, and

where they could easily be suppled with clean fresh water. He thought it would be worth while for the author to turn his attention in that direction. He did not think the paper admitted of much criticism. It was a record of well-merited success, and he was glad to have an opportunity of bearing his testimony to it.

METHODS AND STANDARDS OF PHOTOMETRY.

By HAROLD B. DIXON, M.A.

From the "Journal of the Society of Arts."

In the study of both heat and light we have to distinguish two quantities—intensity and total amount. In the measurement of heat, we are concerned sometimes with the intensity of heat in a body, or its temperature, at other times with the total amount of heat contained by the body. Similarly, in the measurement of light, we may have to determine one of two quantities—first, the intensity or intrinsic brightness of the light; secondly, the total amount of light emitted. The intrinsic brightness of the electric arc far exceeds that of any flame we can produce, but a gas flame with less intensity than the arc may be made to give a better illumination, by reason of the great magnitude of its radiating surface. In estimating the value of any source of light—such as an oil lamp, a gas flame, or a candle—what we are generally most concerned with is the total quantity of light it gives for a given consumption of fuel; in other words, we want to know, when we purchase an illuminant, how bright it will make our rooms, and how long it will last. The intrinsic brightness of the flame, apart from its illuminating power, is but a secondary consideration.

The sensations of radiant heat and light we experience when we stand in front of a coal fire, are produced by the impact of ethereal waves upon our nerves. The red-hot coal is composed of a number of molecules thrown into a state of intense vibration, by the chemical action going on between the air and the surface of the coal. These vibrations are communicated to the sea of ether pervading all space, and are transmitted to a distance as ethereal waves, just as the vibrations of a tuning-fork are communicated to the surrounding air, and are transmitted to a distance as aerial waves. As we stand in front of a fire, these ethereal waves beat upon us, and produce sensations of warmth and light. As the fire dies down, our sensations of warmth and light become feebler; but they do not disappear together. Long after we have ceased to be conscious of any light, we can feel radiant heat streaming from the ashes. On the other hand the full moon at night gives us the sensation of bright light, unaccompanied by any feeling of warmth. Yet the ethereal waves which produce these two sensations differ not in kind, but only in degree. Their undulatory nature is the same, their rate of motion is the same, but some are packed closer together than others, so that they differ in the rapidity with which they succeed one another, and strike upon our senses. Those which succeed one another at short intervals are called short waves, those which follow one another at longer intervals are called long waves.

The total radiant energy of a hot, luminous body can be accurately measured by completely surrounding it with a water jacket, and observing the increase in temperature which the water undergoes in a given time. The ethereal pulsations of every wave-length, radiating from the hot body, are absorbed by the surrounding water, whose molecules take up the vibrations, and are thus set swinging more briskly. This increase of molecular motion in the mass of water can be measured by a thermometer plunged in it. To raise one gramme of water in temperature through one degree, one unit of radiant energy is necessary. If therefore, we know the mass of the water, and we observe the number of degrees through which its temperature is raised in a given time, we have all the data required for calculating the total radiant energy of the hot body. But such an ap-

paratus would not help us to determine the light emitted by a flame apart from the heat. Of the infinite number of waves of different lengths emitted by a white hot body, only a certain few are capable of exciting sensation in the human eye. When the crests of the waves of ether, beating on the eye, are more or less than a certain distance apart, we have no sensation of light. The longest waves that can excite vision give us the sensation of red, the shortest waves give us the sensation of violet. Waves of intermediate length give us the sensation of the other colors of the spectrum—yellow, green, and blue. When waves of all these lengths fall upon the eye in due proportion, we get the compound sensation we call white light. The eye is sensitive to ethereal pulsations only over a very small range. Waves of greater length than those which give us the sensation of red, and waves of less length than those which give us the sensation of violet, produce no sensation of light at all. Since the extreme violet waves are about half as long as the extreme red waves, the compass of our vision is very small compared with our audition, for it extends over a range corresponding with barely one octave.

Several attempts have been made to devise an instrument which should measure the heat produced in the absorption of only that particular set of ethereal waves which affects the eye. Leslie endeavored to measure the energy of the waves that excite vision, apart from the energy of the longer or shorter waves, by receiving the radiations from a luminous body on the bulbs of a differential thermometer, one of the bulbs being of transparent glass, and the other coated with lampblack. His idea was, that the long heat waves would be absorbed by both bulbs equally, but that the blackened bulb would absorb the light-producing waves as well, and so become hotter than the transparent bulb, which would allow them to pass through it unabsorbed. But, as Leslie himself proved, lampblack is a better absorber of heat waves than clear glass, so that the depression of the liquid in the tube connected with the blackened bulb is not to be wholly or even mainly attributed to the light absorbed.

Another and better attempt was made by Ritchie in 1825. The bulbs of his differential thermometer were composed of closed metallic vessels, with one thick glass plate side. Inside each vessel a piece of blackened paper was hung so as to intercept the rays which entered through the glass plate. The two vessels were placed side by side, these glass faces being turned in opposite directions, and one of the lights to be compared was moved nearer or farther away from the photometer, till the liquid in the bent tube connecting the vessels stood at the same height in both arms. Then, if only those rays which produce the sensation of light could pass through the glass plates, and if they were all converted by the blackened paper into heat, the instrument would give a correct measurement of the relative quantity of light rays falling on the two bulbs; but it would not necessarily inform us which of the two lights would appear the brighter to our eyes For unless it could be proved that our sensation of brightness varies directly with the quantity of luminous rays which fall upon the eye, and is independent of their wave-length or color, it might happen that two different sources of light might give out light rays which, converted into heat, would equally affect the two bulbs of the thermometer, and yet might differ in illuminating power, owing to our eyes being more sensitive to the rays of one, than to the rays of the other. But however this may be, it certainly is not the case that only those rays which excite vision can pass through glass and, therefore, Ritchie's instrument does not fulfill the first conditions of a photometer.

A similar objection applies to many other methods of determining indirectly the illuminating power of a source of light. There have been devised excellent means of measuring the amount of chemical or physical change produced by the action of light on certain substances, such as the darkening of silver salts, the combination of hydrogen with chlorine, the decomposition of hydrogen iodide, and the alteration in the electric conductivity of selenium; but such measurements are not determinations of illuminating power, but of certain portions of the total radiant energy of a luminous body, which include more or less completely the rays that excite our vision.

Since, therefore, the object aimed at in photometry is measurement of the effect produced on our eyes by any source of light, it is essential that the eye should be used to receive the rays; and since it is impossible to remember at all accurately, even for a short time, the effect produced on our eyes by any source of light, it is also essential that we should have a constant standard of light, with which to compare other sources of light directly. The production of a standard of illuminating power, with which other illuminants can be compared, and the mode of such comparison, are the two problems in photometry to which I desire to draw your attention.

The official standard used in England at the present time is a sperm candle of six to the pound. This is the standard prescribed by the Metropolis Gas Act of 1860 for testing coal gas. Later acts, and the notification of the gas referees, contained detailed instructions as to the proper mode of employing candles; the candle must be cut in half, and lighted in the middle, so that, while one-half burns down to the thicker end, the other half burns down to the thinner end; the candles must have been burning fifteen minutes before the testing begins, so that they may have assumed their normal rate of burning; the candles must be weighed before and after each testing, and only those candles which burn more than 114 grains and less than 126 grains of sperm per hour are to be considered as standard candles, and a correction is to be made, when the consumption of sperm falls within these limits, on the assumption that the light emitted by the candles varies directly with the sperm consumed. But in spite of these precautions great discrepancies have been obtained by careful operators using sperm candles as a standard of light. On this occasion I can do no more than refer to the experiments of other chemists on sperm candles, among which the ingeniously devised observations of Messrs. Kirkham and Sugg, and the long series of determinations made by Mr. Vernon Harcourt occupy the most prominent place. In consequence of Mr. Harcourt's results, the Board of Trade, in 1879, appointed a committee to investigate the alleged untrustworthiness of the candle standard, and to examine and report upon three proposed standards—(1st) The sperm oil lamp of Messrs. Keates and Sugg; (2d) the gas burner of Mr. J. Methven; and (3d) the air gas flame of Mr. Vernon Harcourt. This committee was composed of Dr. A. W. Williamson, Dr. Odling, and Mr. George Livesey. I had the honor of being appointed Secretary to the committee, under whose direction I conducted the experiments I propose to recount briefly to the Society.

For our standard of light we employed coal-gas, stored specially for our use by Mr. Livesey, in a large gas-holder, at the South Metropolitan Gas Works. We found that the illuminating power of this coal gas remained remarkably constant for a lengthened period, and, therefore, was well adapted for our purpose. In the first place, candles of slightly different make, but coming under the Parliamentary definition of "six to the pound, and burning 120 grains per hour," were obtained from the London firms who manufacture sperm candles of the kind prescribed by the acts, and these candles were compared in an open and also in a closed photometer, with the stored coal gas. The results have been condensed in the following table, which gives the average obtained with each variety of sperm candle tested:

AVERAGE RESULTS.

Maker.	Threads in each strand.	Average consumption of sperm per hour	Illuminating power attributed to coal gas.	Relative illuminating power of candles.
Miller	21	112.6	18.42	94.3
"	18,18,19	110.1	17.37	100
"	21	115.8	19.18	90.6
Langton and Bicknell...	18	116.6	18.35	94.7
Ogleby	21,22,23	132.6	19.0	91.4

Taking the first two sets of figures, we see that the average illuminating power of one variety of Miller's sperm candles is more than 5 per cent greater than the illuminating power of a second variety of the same maker's candles, which only differs from the first in the number of threads in the strands of the wick. Looking at the individual testing made, we find that the illuminating power of the stored coal gas is given on one day

as 16.0 candles, by one pair of candles, and as 18.5 by another pair; while on another day the illuminating power of the stored coal gas is given as 17.1 candles by one pair of candles, and as 19.5 by another.

In order further to test the variations of sperm candles, the committee had a photometer fitted to burn candles at both ends, which were made exactly similar in all respects. Each pair of candles was weighed before and after the experiment, and a corresponding correction was made in comparing their illuminating power for the sperm consumed. Each experiment consisted in taking ten observations at intervals of a minute. The following table contains the corrected results, the illuminating power of the less bright of the two pairs of candles tested being called 100 in every case:—

The letters A, B, &c., represent different varieties of candles, the figures following different candles.

Illuminating Power.		Illuminating Power.
A. 1 = 100	when	A. 2 = 101.6
A. 3 = 100	when	A. 2 = 101.6
A. 3 = 100	when	A. 2 = 101.5
A. 3 = 100	when	A. 4 = 102.5
A. 4 = 100	when	A. 5 = 101.3
A. 6 = 100	when	A. 5 = 105.6
A. 6 = 100	when	A. 5 = 105.2
A. 6 = 100	when	B. 1 = 109.4
B. 1 = 100	when	B. 2 = 105.4
B. 3 = 100	when	B. 2 = 107.4
B. 3 = 100	when	B. 4 = 102.2
A. 7 = 100	when	B. 4 = 105.6
A. 7 = 100	when	A. 8 = 102.8
A. 8 = 100	when	C. 1 = 100.5
C. 1 = 100	when	C. 2 = 105.1
C. 2 = 100	when	B. 5 = 111.7
B. 5 = 100	when	B. 6 = 101.7
D. 1 = 100	when	B. 5 = 104.8
D. 1 = 100	when	D. 2 = 102.8

When the light of two pairs of sperm candles is compared directly in this way, the variations of intensity are strikingly apparent. The following are the actual readings taken every minute, in a test extending over 20 minutes, of the illuminating power of a pair of candles, the value of the other pair being assumed to be 16 in each case. The candles were from different packets, but of the same make. The highest reading is 19.2, and the lowest 16.2, a difference of more than 18 per cent, and within two minutes we find a variation of more than 12 per cent.

A. 16. Illuminating power.	Consumption.	c. A. 15. Illuminating power.	Consumption.
18.6	76 grs.	= 16	70.8
18.3			
18.7			
18.8			
18.9	A. 15 = 100		
18.8			
19.2			
18.9	A. 16 = 100 $\times \frac{18.25 \times 70.8}{16 \times 76}$ = 106.8.		
18.9			
18.7			
18.2			
18.6			
18.4			
18.3			
17.9			
18.2			
17.3			
16.2			
17.5			
16.7			

18.25 mean.

But the most convincing testimony against the candle standard is afforded by our third series of experiments, in which the stored coal gas was tested every day for a fortnight, with candles such as are now being supplied to the testing stations. The candles are sold in packets containing 6 lbs. or 36 candles. We found that candles out of the same packet were fairly uniform in illuminating power. But the average value of the candles from one packet differed very considerably from the average value of the candles from another packet. One packet, composed of fairly uniform candles, gave, as the average result of testings made with ten candles, the illuminating power of coal gas as 15.0, and another packet gave as the average result of testings made with ten candles, the illuminating power of the same gas as 17.2. The table (p. 274) contains the averages of at least ten candles from each packet.

In a parallel column are printed the results of testings made with Mr. Harcourt's air-gas flame of the illuminating power of the coal gas during the fortnight these experiments lasted.

Since the report of the committee was issued, Mr. Giroud has published experiments made with standard sperm candles, in which he tested them against each other, and against a standard gas flame. The results he has drawn up in a series of diagrams which show the position of

VALUE OF STORED COAL GAS AS GIVEN BY

Date.	Standard Candles.		Air gas flame
	Packet.		
March 23	A.	16.19	
" 24	B.		15.9
" 25	B.	15.26	—
" 26	B.		—
" 27	C.		16.05
" 29	C.	15.21	—
" 30	C.		—
" 30	D.		—
" 31	D.	15.25	15 95
April 1	E.	15.02	15.9
" 2	F.	15.88	15.95
" 3	G.	16.87	16.2
" 5	H.	16.72	16.1
" 6	I.	16.24	16.2
" 7	K.	17.26	—
General Average....		15.99	16.02

the screen between the two candles, and between the candle and the gas flame, at each reading of the photometer. These diagrams reveal in a striking manner the rapid alteration from minute to minute in the intensity of light of a standard sperm candle.

Count Rumford, in experimenting with his shadow photometer, discarded the candle of his day in favor of an oil lamp, with a circular wick, as a standard of light. By means of this oil lamp he was able to prove experimentally that the illuminating power of a source of light varies in our atmosphere inversely as the square of the distance, and therefore, that the absorption of light by several feet of air is inappreciable.

An oil lamp, with a circular wick, burning purified colza oil at a certain rate, is used in France as the standard of light. Messrs. Keats and Sugg have introduced modifications into the French carcel lamp, and propose to employ a lamp burning pure sperm oil, with a two-inch flame as a standard. The lamp so contrived gives a brilliant and steady light, but unfortunately, the long wick sometimes becomes so brittle, when charred, that any adjustment of its length becomes impossible without danger of breaking it. The objections which apply to a candle as a standard, also apply, though in a less degree, to an oil lamp. The exact nature and form of a burning wick are incapable of accurate definition, and since the illuminating power is largely dependent on the nature of the channel which supplies the combustible to the flame, no standard seems likely to be trustworthy whose constancy depends on the uniformity of a wick.

Mr. Methven has devised a plan by which he proposes to measure the illuminating power of coal gas, by cutting off a small portion from the center of the flame of an argand burner, supplied with the same coal gas as that to be tested, and using that isolated portion as the standard of light. The argand he employs is the same "London Argand" used to burn the coal gas at the testing stations. In front of the lamp, between it and the screen, a brass plate is fixed, carrying a small thin silver plate, in which a slit one inch long and a quarter of an inch wide is cut. The plate prevents any other light, except that which passes directly through the slit, from reaching the photometer. The height of the flame is adjusted as nearly as possible to three inches, though small variations in the height of the flame do not affect the quantity of light which passes through the slit. We found that there was no appreciable difference when the flame was raised or lowered a quarter of an inch from the normal height. From this description, it will be evident that Mr. Methven's method is exceedingly simple, and little or no trouble is required to prepare the standard for use. The principle on which Mr. Methven founds his method may be thus stated: When different qualities of coal gas are perfectly burnt in an argand burner, at such rates as to yield a three-inch flame, the central portions of such flames will be equally bright, no matter what may be the quality of the coal gas supplied to the burner. A rich gas will give a flame which begins to be luminous nearer the orifice of the burner than the flame from a poor gas; but the screen, by cutting off this lower portion of the light, equalizes the two, as seen through the slit. To test the lamp, the committee conducted two series of experiments, using coal gas of different qualities to supply the Methven burner; the first series were made at the London Gas Works, the second, at the South Metropolitan Works.

The following Table gives the result of the first series:

Gas used at Standard Burner.	1. 21 candles.	2. 19 candles.	3 16.5	4. 14.
Value assigned to stored common gas	17.11	16.90	17.08	17.15
" " "	17.08	16.89	16.92	16.93
" " "	—	16.92	16.86	16.95
" " "	—	—	16.92	16.99
" " "	—	—	—	17.04
Mean.....	17.1	16.9	16.9	17.0

In these experiments, the two intermediate qualities of gas were prepared by mixing the cannel gas of 21 candles with air. The excellent results obtained in this series were not repeated when the lamps were supplied with varying qualities of coal gas, obtained from the retorts at different periods of the distillation of ordinary coal. The rich gas used was that given off by ordinary coal during the first hour of the charge. The poor gas (13.6 candles) was made by mixing gas from the sixth hour of the charge with ordinary gas. The intermediate qualities were made by mixing the rich or the poor gas so collected with ordinary gas.

In the following Table are given the results obtained with Methven's burner, supplied with these different qualities of coal gas, and used to test the stored coal gas at the South Metropolitan Works:

1st Set. Dec. 1880.

Value in candles of the gas burnt at the Methven burner.....	13.6	14.3	14.9	15.5	15.8	16.4	17.6	19.0	19.6
Value in candles assigned to the stored coal gas...	21.2	16.6	15.6	15.2	14.9	14.5	14.6	14.5	14.0

2d Set, with Fresh samples of Gas. Jan. 1881.

Value of the gas burnt at the Methven burner.....	14.4	15.5	16.2	17.3	18.5
Value assigned to stored coal gas.....	15.1	14.4	14.3	14.4	14.1

From these figures, it appears that variations in the composition of the gas may influence the light yielded by the Methven burner, and consequently some check on the Methven burner becomes necessary, in the absence of which grave errors might pass unnoticed in the estimation of a sample of coal gas. It is true that the Methven burner gives accurate results when burning the coal gas, generally sent out by the large London gas companies, and supplies a want felt by many gas managers—that of a rapid and easy method of testing their make of gas at any moment. But it is essential for a standard of light to be independent of any fluctuations in the quantities to be measured by it, and this quality the Methven burner does not possess in its present form. Mr. Methven is at present engaged in perfecting his burner, and, I believe, will shortly bring forward a lamp, better adjusted to give a constant light, with varying qualities of gas.

In Mr. Harcourt's air-gas flame, the supply of combustible matter to the flame can be adjusted with extreme accuracy. An illuminating gas, especially prepared for the purpose, is burnt from a large orifice in a brass burner, at such a rate as to produce a flame $2\frac{1}{2}$ inches high. All the conditions of burning are capable of exact definition. The combustible matter is a certain portion of purified American petroleum, consisting mainly of the hydro-carbon pentane. The presence of higher and lower members of the paraffine series, which occur in American petroleum, such as hexane and tetrane, does not alter the illuminating power of the air gas prepared from pentane, when these bodies are present in such quantities that the specific gravity of the mixture does not vary beyond certain wide limits. In practice, therefore, Mr. Harcourt does not separate pure pentane from the purified petroleum, but separates a liquid having a specified gravity closely approximating to that of pure

pentane, but containing, besides pentane, some tetrane and hexane. In this way, a fair proportion of standard petroleum is obtained from the crude gasoline imported into this country from New York. To try Mr. Harcourt's system, the committee first tested the stored coal gas at the South Metropolitan Works with samples of air gas prepared from different makes of standard petroleum, using alternately that of the highest and lowest specific gravity yielded by the process of separation. No difference could be detected in their illuminating power. Samples were next prepared and tested against the stored gas by different observers, with the same result. Then the apparatus being set up in duplicate, one air-gas flame was tested against a second, in the same manner as candles had been tried against candles. The results so obtained were concordant to a surprising degree of accuracy. I give two of the sets of readings taken, the illuminating power of one flame in each case being called 16, and each burner being supplied alternately from each holder.

1st Holder. Left-hand burner. Observations every minute.	2d Holder. Right-hand burner.	2d Holder. Left-hand burner. Observations every minute.	1st Holder. Right-hand burner.
(1.)		(2.)	
16.1	16	15.95	16
16.0		16.0	
16.05		16.05	
16.0		16.0	
15.95		16.05	
16.0		15.9	
16.0		15.95	
16.05		16.1	
15.95		16.0	
16.0		16.0	
Mean. 16.06		Mean. 16.00	

Two objections have been raised against Mr. Harcourt's system; first, that it requires such skill and care in the operator as to unfit it for general use, and, secondly, that the meter and governor employed are on so small a scale that they cannot be made to work efficiently. In answer to the first objection I should reply that skill and care are needed in working, but not such skill and care as cannot be found among the expert and conscientious chemists, who at present test the coal gas of the metropolis. On this point I can speak decisively. Mr. W. G. Wood, one of the official gas testers, after one day's instruction, was not only perfectly able to adjust the air-gas flame, and obtain exact readings of the value of the stored coal gas, but prepared a sample of the air gas from the standard petroleum, which gave exactly the same result as previously prepared samples. In answer to the second objection, that of the difficulty of constructing for the air-gas flame a sufficiently delicate governor and meter, an objection which has, I believe, been urged by those who make, and who therefore ought to understand them, I venture to reply that the makers underrate their own ability, and that the accurate working meter and governor before you, constructed by Messrs. Wright & Co., is sufficient evidence to completely dispose of this objection.

The method of comparing the illuminating power of two sources of light, by observing the distances at which the two lights must be placed from the screen, so that the portions illuminated by each shall be of equal brightness, was first adopted by Bouguer in 1729. Bouguer placed his lights behind a transparent screen, so arranged that one-half of it received the rays of one light only, and the other half the rays of the second light only, falling nearly perpendicularly on it. Exactly the same arrangement was afterwards adopted by Foucault in his photometer, who employed for his transparent screen two sheets of glass, pressing a uniform layer of starch between them. Rumford, in 1792, addressed to the Royal Society a description of a photometer, in which the two halves of a paper screen were severally illuminated by the rays of two lights falling at an angle of 60°. The observer sat facing the screen with the two lights behind him, one on each side. Two small wooden uprights served to protect from the rays of one light that half of the screen illuminated by the rays of the other. Each upright had attached to it a supplementary strip of wood, which, by turning the upright round, could be brought to project into the light, and so increase the width of the shadow thrown

on the screen. By this arrangement, the shadows thrown by each upright could be made to accurately coincide, and the eye had less difficulty in judging when the two portions of the screen were equally bright, because they then presented one homogeneously illuminated surface. Mr. Vernon Harcourt, in his new photometer, which by his kindness I am able to exhibit for the first time this evening, has adopted a somewhat similar arrangement for his screen. The lights, as in Foucalt's photometer, are placed behind the screen, which is made of ordinary printing paper, No. 23, washed with water, and painted with a solution of spermaceti in petroleum. In front of the screen, and at a distance of about $\frac{3}{4}$-inch, is placed a brass diaphragm, having two similar vertical slits cut in it, side by side, at a distance apart equal to their own breadth. The two lights to be compared are similarly placed on each side of a line drawn perpendicular to the screen. Their rays fall at such an angle that the shadow thrown on the screen, owing to the solid piece between the two slits stopping the rays of one light, is exactly illuminated by the rays of the other light passing through one of the two slits.

By adjusting the distance of the brass diaphragm from the screen, it is easy to make the shadows accurately coincide, so that when the central portion is as bright as the two outside portions, the screen presents one homogeneously illuminated surface. With this photometer, I have recently made a few experiments in Mr. Harcourt's laboratory; and I have taken from his note book the following numbers, which represent independent tests of the illuminating power of a small sample of coal gas stored in the laboratory:

Illuminating power of stored coal gas.	Observer.	Date.
16.5....	H. B. Dixon.	Dec. 8th, 1881.
16.3....	A. V. Harcourt.	
16.5 ...	H. B. Dixon.	
16.4...	A. V. Harcourt.	
16.5....	H. B. Dixon.	
Mean 16.4		

Illuminating power of stored coal gas.	Observer.	Date.
16.5....	H. B. Dixon.	Dec. 9th, 1881.
16.5....	"	
16.5....	"	
16.5 ...	S. E. Miller.	
16.5....	"	
16.5....	"	
Mean 16.5		

In this photometer, the two lights and the disc are kept stationary, and the equality of the shadows is obtained by adjusting the coal gas supply. The photometer tells us at what rate we must burn the gas in order to obtain a flame of 16-candle power.

Bunsen was the first to employ a disc, having a portion of it made more translucent than the rest, and placed between the two lights to be compared. When such a disc is illuminated more strongly in front than behind, the translucent spot seen from the front, appears dark on the bright ground, while an observer behind the disc sees the translucent spot bright on the dark ground. When the disc is equally illuminated on both sides, the spot appears neither brighter nor darker than the rest of the disc. In the official measurement of the illuminating power of London, coal gas, the Bunsen disc is employed, and either the lights are kept stationary, and the disc moved, or the gas flame and disc are kept stationary, and the candles are moved until equal illumination is obtained. The distance of the two lights from the disc are then read off, and the squares of those distances give the relative illuminating power of the lights.

Since the light of a sperm candle is redder than the light of a common gas flame, it is impossible to adjust the photometer so that the two sides of the Bunsen disc appear alike. In using the Bunsen and the star disc I have generally adjusted the distances of the lights so that the circle or star appeared equally distinct on both sides, the pattern enabling one to form an idea of distinctness apart from color. But though extremely close readings may thus be obtained with the same disc, a change of disc, or a mere reversal of the same one, occasionally introduces a considerable

variation in the apparent illuminating power of the coal gas. On the whole, therefore, I consider the shadow photometer the fairer instrument.

Another method of determining the equality of two illuminated surfaces was first proposed by Arago. When a beam of light passes through a crystal of Iceland spar it is divided into two rays, polarized at right angles one to the other, called the ordinary and the extraordinary rays. A nicol prism is formed of two pieces of Iceland spar, joined together by Canada balsam in such a way that only one of the two rays, into which the beam is divided, passes through it. Now, if the light from two equally illuminated surfaces is allowed to pass through a crystal of Iceland spar, we see four images of the two surfaces, because each beam of light is divided by the crystal. If the size and position of the illuminated surfaces are so arranged that the extraordinary image of one just coincides with the ordinary image of the other, we see three images on looking through the crystal, but the double image is, of course, brighter than the other two. The brighter image is really composed of two images, superposed one on the other, and if its two components are of equal intensity, the resulting light is ordinary unpolarized light. The other two images, composed of polarized light, will exhibit colors when examined by a thin plate of selenite, or by a plate of quartz, cut at right angles to its axis, combined with a suitable analyzer. The central image will also exhibit colors, when thus examined, if its two components are not of equal intensity; for in that case there will be a surplus of one kind of plane-polarized light over and above that required to neutralize the other kind. The lights are therefore adjusted, until an observer, looking through the instrument sees the central image white, while the two side images are colored with complementary colors. The two lights are then of equal intensity. In this form of photometer, it is essential that the two lights should be of the same color exactly, otherwise the color changes of the polarized light are valuless as indications of intensity. This objection to the instrument has prevented its adoption for testing the illuminating power of gas by comparison with a standard candle.

Several methods have lately been devised for comparing, by means of the polariscope, the intensity of corresponding portions of the spectra of two lights of different color. Such methods give an accurate measure of the relative intensity of individual colors present in both lights, but they do not compare the total intensities. Again, by superposing such portions of one spectrum as yield a tint similar to the tint of a portion or portions of the second spectrum chosen for comparison, a nearer approach to an accurate measurement of the total intensity may be reached; but since only some fraction and not the whole spectrum is taken, an approximation to the truth is all that can be obtained. Instead of comparing portions of the spectra of two sources of light, it is more simple to look at them through colored glasses; in both cases only some fraction of the light is measured, and it can make little difference in the result, whether certain colors of the spectrum are cut off from the photometer by a diaphragm, or are absorbed by a colored glass. In a small portable photometer, designed by Professors Ayrton and Perry to compare lights of very different intensity and color, such as electric lights with a sperm candle, the brighter light, before falling on the screen, is diminished by passing through a concave lens, whose distance from the screen can be adjusted till the intensity of the more or less diverging ray is equal to that from the candle. The two shadows are compared first through ruby-red glass, and secondly through signal-green glass. Since the electric arc is comparatively richer in shorter waves than the candle flame, the shadow comparison is more in favor of the electric arc with the green glass than with the red. Messrs. Ayrton and Perry do not give the mean result as the relative illuminating power of the arc and candle, but admitting the impossibility of truly comparing two different colors by eye, give both results as indicating the relative intensities of the two sources of light for the particular light waves severally transmitted by the two colored glasses.

THE second 80-ton gun for the turret has been successfully landed at the Admiralty Pier, Dover.

TRESTLE BRIDGES AND MODES FOR MAINTAINING THEM.

By J. H. CURTIS, C. E.

From the Papers of the Pi Eta Society.

In the construction of trestle bridges as a means of quickly repairing a break in a railroad, due to the burning or failure of a permanent structure, the best practical skill and ingenuity of our profession are in demand. Little information can be obtained from books on this subject, and only that far-seeing judgment and quick perception which constitute the shrewd practical man are of any value in such an emergency. The object is to do all that is required, often having little with which to do it. To remove a mass of earth in case of a wreck, to plant mud sills and to carry forward the carpenter's work with such rapidity that, by the time the ground is cleared, an entire line of trestles is ready for erection, is a requirement difficult to comply with. Little care can be given to the preparation of the timber. A builder's level and a tape measure in the hands of the one in charge, with cross-cut saws, squares and plumb lines, comprise the necessary instruments and tools for the work. To begin the work, project an approximate center line of the track over the break, and on this drive pegs a panel distance apart to locate the base timbers, or "mud sills," as they are usually called. If the structure is to be more than one story high, assume the height of the first story, giving attention to the lengths of the timbers so that they will work economically, and not be wasted in cutting. Take the greatest pains in planting mud sills to make them firm and level, otherwise there will be no end to trouble, both in construction and subsequent settling; at the same time be regardless of their relative height, but adjust that matter in the lengths of the verticals. By establishing a straight edge on the embankment at one end of the track parallel to the track grade, and at the height of the first story, an observer stationed there can range along the entire work, and separately, for each bent designate the heights of the upper cap surface above the mud sills by means of a level rod held thereon, or what is better, a straight stick lifted vertically to line of sight and the proper lengths cut off to serve as a measure. Each vertical will have its length less the thickness of the cap stick and surface sill for its respective bent.

Thus the work is distributed over the entire break. Each bent should have from two to eight verticals, the number depending upon the width and height of the structure. Care should be taken to have all the timbers squarely sawn and the cap sticks, perhaps the surface sills also, securely fastened to them before the bent is raised, as it can then be best "squared" and the bases "scribed in." Commence erecting the bents as soon as any two consecutive ones are framed, securing a connection with the embankment as soon as possible, that the stringers may be run out and a portion of the track placed in working order, or another story added, as the case may be, and all hands be constantly employed. With due care in framing, all the cap sticks will have nearly the same height; however, any slight differences existing produce no serious inconvenience, as the stringers may be "sized on," that is, worked down at the bents where the cap sticks are most elevated until they rise evenly on each. Should a cap stick be exceptionally low, a piece of timber of the required thickness may be spiked on to it and the stringer notched or worked into this. Wedges should not be used for this purpose, as they are liable to be jarred out. Having done all this, it will be found that the stringers are not quite parallel to the road grade, but have small inequalities; this is obviated by working the sleepers to the required thickness. If the trestle is to be only for temporary use, an additional width should be given it, and the cap sticks have at least a length of twenty feet for a road of single track. On these the lower chords of the bridge, which is to replace the temporary structure, may be placed the trusses assembled, and in order not to impede the

traffic while the cross girders and braces are being placed underneath the track, it may be bodily lifted and blocked up, to be lowered again when everything is in readiness, and the bridge swung.

Care must be taken to brace every part of a trestle. A system of horizontal braces between caps is desirable, as it serves to take up lateral oscillations, which tend to throw the track out of line—a thing to be closely guarded against. This difficulty is increased if the foundations are bad, and no subsequent work will entirely remedy it, the only alternative being to line up the track. Therefore, look well to the foundations. Any ordinary soil is sufficient if well drained and the sills placed below frost. If partially dry quicksand is encountered, an excavation can be made and the bottom covered with a foot of gravel. I have obtained good results on oozy and mucky ground by placing a few inches of sand in the excavations. The object secured was the prevention of water being forced out during the passage of a train, to be returned by the pressure of the atmosphere. As regards trestles in flowing water, affairs become complicated. Any obstruction causes a disturbance of the water, and if the bottom is of a yielding character, a scouring action takes place. However, trestles may be protected against this, even in wide and turbulent rivers by taking the proper precautions. I will first note the difficulties, then give a remedy. I cannot enter into all the details of the subject, but will give some facts which I have observed in regard to the drifting of sand, due to the mechanical action of flowing water, a description of which was made in a report to the U. S. Engineer Department some time during last September. The water in flowing rivers does not move forward in horizontal layers, as many writers have said, but is continually revolving in vertical curves, impinging against the bottom, then coming to the surface loaded with sand and again descending; in fact, simply rolling, propelled by gravity and revolved by reason of contact with the bottom. Its mean velocity is, perhaps, measured at mid-depth or a little below.

Now, if the mechanical action of the flowing water on the bottom is uniform for any considerable portion of the river, there will be no scour nor fill, as the material carried forward will be replaced by other material from above, the quantity depending, in a great measure, on the velocity and volume of the river, and in its movement, being governed by the same process as the flowing water, viz., gravity and resistance due to friction on the bottom, giving it a rolling motion. Just in what manner the water acts on the bottom of the river is unknown, but some of its results have been determined. During a series of discharge and sediment observations made on the Arkansas River, at Pine Bluff, extending over a period of six months of last year, great care was given to a study of this subject, and the rolling motion of the bottom to a variable depth was discovered; this depth was never less than five inches at extreme low water, and in high water was greatly increased. It was found that the movement partook of the form of sand waves, sloping gradually upward and abruptly downward in the direction of the stream.

These waves traveling at an average distance of 22½ feet apart during low water, represent the successive forms of rolling sand. The long inclines are scoured off, drifted over the crests and deposited, there to remain until the entire wave passes over, to be again picked up and deposited as before. By careful observations, the contents of this moving volume were measured from day to day; it was found that in very low water and in a mean current the sand waves had a height of only ten inches and no perceptible movement, but with a slight rise they would start forward and the volume discharged seemed to have a ratio to the discharge of water. During thirty-five days at Pine Bluff, from June 10 to July 15, 1879, the discharge of sand and of water had a ratio of one cubic foot of the former, to 440,000 cubic feet of the latter, and these observations taken at the time of very low water, showed this volume to be smaller than that carried entirely in suspension, both in bulk and weight. I have no doubt the ratio would be enormously increased in time of flood, but unfortunately there was no high water during the time of the observations, to give opportunity for experiments, but I know that waves five or six

feet in height were incidentally found at a stage of 18 feet above low water, where the maximum high water stage was 30 feet.

I have thus called your attention to bottom drift in alluvial rivers, in so far as it relates to our subject, but the investigations which have been made to determine the above facts, would be unnecessary.

From this it can be seen that low water is the only condition in which the bottom of an alluvial river is sufficiently quiet to permit of a trestle being placed in it, but this once done, there remains only to protect it from the scouring action of the water, occasioned by even the smallest rise.

First, the trestles should be made of piles well driven down, to insure stability (although in a navigable river this might ruin navigation), and located in a wide shallow crossing, immediately after a sudden fall of the river, before the high water deposit has been scoured out.

Mattressing should accompany the trestling, so that when the latter is finished, the bottom of the river will have a brush carpet from shore to shore, extending above and below the trestles at least fifty feet.

The mattresses should not be over a foot thick, the size varying according to the depth and velocity of the water, and the circumstances under which the work is done. Usually, a large mattress would be preferable to a smaller one, as the cost per foot is less, and under favorable circumstances it might possibly be woven continuously from shore to shore, the whole work consisting of one piece, in which case the amount of small stones necessary to hold the work in place until it should fill with silt would be very small.

RAILROAD ECONOMICS, OR NOTES AND OBSERVATIONS FROM THE OHIO STATE RAILWAY INSPECTION SERVICE.

By S. W. ROBINSON, C.E., Prof. Mech. Eng. State University, Columbus, Ohio; Member of the Board of Inspectors under the Hon. H. Sabine, Commissioner of Railroads and Telegraphs.

Trunk and other Lines.—In Ohio, as well as in at least two other States, there appear to be two classes of railroads,—first, the great trunk lines connecting the West with the East, and, second, those having largely or altogether local interests. The former are most likely to run east and westward, while the latter run mostly north and southward. Strong companies control the former, while the latter often fail to pay well enough to keep up repairs. In many instances a weak company sells its interests to a stronger, when the former causes a general need of repairs. The strong company or trunk line then puts the road into good running condition, sometimes to form part of a through line, sometimes a branch, and sometimes to form a tributary to it. In this way a road of secondary importance may be kept up to good running condition, while otherwise it would go down.

Whatever may be said against consolidation of railroads, it appears to be a fact that roads owned by strong and wealthy companies are in far better condition than otherwise. Indeed the generally good condition of the great trunk lines and of their branches is a credit to those companies. If these roads are backward in some things, such as introducing the best systems of "signaling," "blocking," and of "interlocking apparatus," they are certainly up in other matters, such as steel rails, iron bridges, &c.

Safety.—A little attention to railroading will suffice to show that safety in railroad travel is the price of incessant vigilance. That a stretch of three hundred miles, extending across a state is, every foot of it, perfectly safe to-day, is not proof positive that it will be so to-morrow, though the broken rail or washed culvert is the subject of constant search.

Protection of Railroad Structures.—The life of railroad plant is not great. New roads, with iron rails and wooden structures, will need renewals for the most part within ten years. Rails endure according to traffic, and for light traffic will run ten years. Ties will rot out in from five to eight years. Culverts, cattle guards, &c., about the same. Good

wooden bridges, when new, will be dangerous in ten years unless covered. If covered at all it should be done within two years after building, otherwise the timber becomes affected with dry rot at the the heart. This decay might perhaps better be called *blind rot*, because it is hidden. A wooden bridge, nicely covered and painted, may *appear* to be in the best of condition, but really be in the very worst. Joints in the lower chord of such bridges are seen to be pulling out by the locks splitting off. In such cases, when the timbers are sounded with a boring bit the latter will find sound wood for two or three inches, when suddenly the bit may take a jump of four or six inches through a dry rot hole. Such well-covered and well-appearing bridges are found not to have been covered under about three years after building. Equally good uncovered bridges, even better, ten years old, have been found than those of equal age, well covered, in which the covering was delayed three years. It appears that after three years of exposure to open weather, a bridge is doomed to a life of only about ten years covered or uncovered.

But by prompt covering of wooden bridges the life is more than doubled, from which it appears that the practice of covering such bridges is highly economical.

It is sometimes the practice to cover simply the trusses, and it is necessary in "half Howe" or "pony trusses of wood. This leaves the floor system exposed, and any sap wood about the floor-beams or the stringers is soon eaten away with decay. Sap is of but little worth after three years' exposure, even when free. But heart wood is often perfectly sound at ten or fifteen years. Sap wood is so comparatively worthless that some engineers specify that not over eight per cent. of section of timbers shall be sap. It is an excellent precaution to thus limit the sap wood, because it is practically of no value. In existing bridges sap wood rot has reduced the section of chords, as estimated, from ten to twenty per cent., the remainder being sound. Uncovered flooring should, therefore, be watched, and when the beams are found weak, as by observed excessive deflection, new beams should be added.

Painting is an excellent practice, and its power for prolonging the life of wood is not confined to free or external surfaces, but internal as well,—that is, to illustrate, lower chords have been examined where the wooden "clamps and keys" were laid in white lead, or sometimes in red lead, and such are sound and strong to a greater age than unpainted.

A close joint in wood, where exposed, is far worse than open joint of small space sufficient for air to pass. From this fact it appears that wood contacts have been avoided by using iron "clamps and keys" in lower chords. Some engineers make iron clamps or blocks with a space for ventilating between wood and iron, the bearings being quite narrow. These have given good results, and point to the value of ventilation.

As to ventilation in general, all coverings should leave the main bridge timbers free for air to circulate about them. For instance, the boarding along the sides of trusses should be firred out by girt strips being nailed to the truss along the braces above the lower chord and below the upper chord, and not on the chords themselves. Then, when the boarding is nailed upon these girts, it stands out free, so that air can freely go all about the chords.

In some instances chords have been found covered with tin, the same being fitted about the braces and nailed to the chords, so as to appear like giving protection to the chords beneath. But this is believed to be worse than no covering whatever from the simple facts that, first, water will work in at the numerous joints, and, second, be held there by the tin covering. If the tin could be carried away from the wood by a 2″ space, the latter being allowed for ventilation, it will serve a good purpose when it is made tight. These conditions are readily met in "combination" bridges, that is, in such as have wood upper chord braces and end posts, but with iron ties and lower chords. The upper chords are readily covered with tin, because nothing protrudes above to prevent. The braces, or vertical pieces generally, do not need covering, as it is found that the wet so rapidly escapes as to leave the braces soon dry.

Special pains should be taken to keep wet out of close places in wood. For instance, in deck bridges (Howes), water is apt to leak through the roof, as it is

difficult to lay a roof among the ties, floor beams, string, &c., in the floor system and get it tight. In such cases the sway braces are apt to carry the water which falls upon them down upon the lower chord. This has been avoided very neatly, cheaply, and efficiently on the Lake Shore and Michigan Southern Railway, by making a saw cut across the top and edges of the sway braces, and driving in a collar of sheet iron or tin, which extends down like spurs below, and thus heading off any water which may find its way through the floor or roof above, and alight upon the sway brace to come trickling down upon the lower chord.

But though tin may be suitable to cover upper chords as above explained with reasonable durability, yet as a main roof covering over the tops of Howe bridges it appears to be utterly worthless, for the reason that the sulphurous fumes of the smoke from the locomotive soon eats the tin roof through like a big pepper-box lid. Indeed this action upon iron has been observed upon heavier masses of iron than tin; the truss rods even having been observed in badly rusted or pitted condition, with a weakening of probably five to ten per cent. The latter has been observed to be most serious in low lands, such as would be frequented by fogs. The moisture of the latter deposits upon the rods and absorbs the acids of the smoke. The iron is then etched more or less seriously. Rods for such localities should be made with some excess of section to provide for the corrosion.

Wooden Bridges.—The prevailing wooden bridge is the Howe truss. It consists, as generally put up, of an upper and lower chord, connected by vertical tie-rods running through with nuts at both ends; the latter dividing the span into panels containing braces and counter braces. The chords usually are made of four sticks, side by side, with blocks or "keys" notched in, but leaving a space between all the sticks. Chord bolts run through from side to side of chord to draw all together. In short chords the sticks run from end to end. But for lengths greater than about forty feet, pieces are put in so as to break joints. In upper chords these simply abut against each other, but in lower chord clamps are used to make tension splices. These clamps are generally of oak wood, and preferred by some builders of the first and by some of the second form in Fig. 1. Sometimes only one is used to a

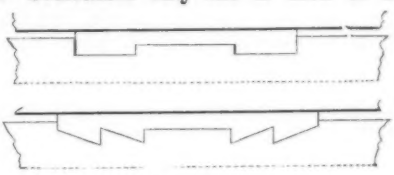


Figure I.

splice, as shown, but more often two, one on each side of pieces joined. A chord bolt goes through near each end of a clamp. The earliest point of failure in a wooden bridge is at the locks of these clamps, either on the clamp itself or on the interlocking hooks of the chord.

Two of these splices are never found opposite in a chord, but break joints, so as to allow one joint to each panel. In this way the so-called keys help to form the splice. There are always two main braces and one counter brace between in each panel. The former always incline toward the middle span point. In moderate spans there are always two tie-rods at each inter-panel point, but in long spans there may be three at the ends of truss. The largest of these rods are 2″ in diameter; almost always threaded without enlargement of ends. These ties draw against straps on the outside of the chords, running from 1″×5″ down to ½″ × 3″ in section, and long enough to extend the width of the chord. The braces almost always set square against iron angle blocks. The best of these blocks have flanges to prevent the braces from falling out of place. These blocks are often found broken, but the breakage is evidently due to carelessness in drawing up the tie rods too tight upon the braces, because on some roads these breaks are very numerous, while on others the same make of blocks are never found broken. Road masters say they find difficulty in getting men to draw their ties up properly upon the braces.

The depths of these trusses vary. Short spans, or "pony" trusses, sometimes also called half trusses, run from about eight to twelve feet height. Full trusses for longer spans are usually about twenty feet. The smaller trusses have about three or four floor beams per

panel, while the larger have five. They always rest upon the chords.

When wooden bridges show signs of failure the speed of trains is often reduced till a remedy is applied, either in strengthening the bridge or by renewing it. Two ways of strengthening a lame bridge are in use. One consists of springing a wooden arch from the abutment, usually from iron skewbacks, placed about six feet down, and rising at mid-span nearly to the tops of the trusses. Each case requires four arched ribs, one on each side of each truss. From the arches the trusses are suspended by rods. But this method is too expensive for an old bridge; it is more common for a light bridge otherwise good. The second way to doctor the bridge, and which is very common for old bridges, is to put a trestle bent under at the third or quarter span. A pile bent is sometimes used instead of a trestle bent. The objection to placing the bent at the middle is the fact that the counter braces near the middle in that case become main braces. Some less considerable road masters place the doctor at the middle, however. But as the carrying power of a truss varies inversely as the square of the span, other things being equal, it appears that the strength of a bridge is nearly doubled by placing a support at the one-quarter point. Such trestle bents are carefully watched to guard against washing out by the stream. In high water such a trestle bent is a treacherous affair, a pile bent being far preferable.

The lateral bracing in bridges is almost always about the same, viz., about 6×6 braces and $1\frac{1}{8}''$ tie rods, and the same from end to end of bridge. These are usually in the plane of the lower chords and also upper. No difference is made in the strength of the lateral bracing, as far as observed, for straight or curved track, though it is certain that the centrifugal force of a train running on the curved track over a bridge will give cause for lateral thrusts, which are considerably greater than for straight track. One element of compensation, however, exists in the fact that bridges under curved tracks are usually wider, so as to allow equal clearance room, and this gives wider lateral trussing. Trusses are not found inclined on account of curves on the bridge.

Through bridges of wood have no "sway" bracing. The chords of the trusses are from 24″ to 30″ in breadth, and the floor beams extend entirely over to the outsides. This keeps the lower chord in position. The braces cover about the whole width of the chords, so that the trusses are quite stable in erect position.

Deck bridges always have sway bracing, but in some cases much stronger than others. Where several spans of wood bridges are contiguous, in some cases both or all are made continuous from span to span. In other cases only one chord will be continuous. Diagrams taken, as hereafter explained, have shown that in continuous two-span bridges an appreciable rise of the second span occurs when the train gets fairly on the first.

Iron Bridges.—The prevailing form of iron bridges is the Pratt truss for long spans, and for short the plate girder. The change from one form to the other occurs usually at lengths between sixty and a hundred feet. These statements apply more definitely to recent practice than former. The older iron bridges are very promiscuous, both as regards form and manner of putting together. Some of the first iron bridges in the State were Howe trusses, one of which went down in the Ashtabula disaster. But in place of the latter we now find what is probably the strongest iron Pratt truss in the State, so that people need not now go around Ashtabula to avoid a second catastrophe.

The parts of truss bridges were formerly united in various ways, sometimes by bolts, notches and locks, and often by riveting in place. But at present the method by pins and eyes prevails, especially for the longer trusses. In upper chords, however, though the tie rods are usually attached by pins, yet for increasing the rigidity they are made continuous by riveting on splice pieces extending past the pin holes. The forms of parts of bridges, as well as the methods of joining, are almost as though stereotyped. Thus the "eye-bar" is an article of manufacture, and is used in all parts of bridges except upper chords and struts or columns.

Upper chords and end posts are most frequently made of two channel bars,

twelve to eighteen inches apart, with webs vertical. They are joined on top by a longitudinal plate extending the whole length and riveted to the flanges, while the bottom side is latticed or "laced." "Webb" members serving as struts are most frequently composed of two channel bars at a distance apart, and connected by diagonal lattice slats riveted on. Sometimes, however, the two channel bars are riveted by their webs to the flanges of an I-beam. Formerly Phœnix, Keystone, Box and other columns, nearly or quite closed, were much in use, but they appear to have given place almost entirely to such open columns as above mentioned, simply from the necessity experience has developed of painting every inch of surface in iron bridges.

Most engineers require forms such that a paint brush can touch every part, either inside or out. The advantage of this is seen from the fact above mentioned of the rusting of truss rods and of tin roofs from moisture and smoke. The statement also, which has come to my notice, that tons of rust have been removed from tubular bridges, is in point.

Floor-beams, made by riveting four angle bars upon the edge of a plate—two upon each edge at opposite sides—are the most common. The section approaches that of the eye-beam. Plates are often riveted on top and bottom, part of the length, to increase the strength at the middle part where the moment of strain is greatest. These beams are most frequently suspended from the pins of the trusses by inverted "Ω" bolts. But when there is scant room below a bridge for water way or otherwise, they are in some cases riveted to the vertical struts.

The stringers are most frequently of rolled I-beams.

The lateral stiffening is much better attended to in iron bridges than in wooden ones. The lateral ties not only vary in size, from end to middle, but differ in size according to span, width, &c. There is generally a lateral system at both the bottom and top chords.

Plate girders are usually formed by riveting angle bars to the sides of the webs, top and bottom, then across these a flange. The latter is increased by additional "lifts" laid on the middle portion. These plate girders are usually of uniform depth, though some have been met in which the upper flange or chord was arched so as to nearly join the lower chord at the ends. Vertical stays of angle bars are riveted to the web throughout these girders, but nearest together at the ends, their object being to prevent the buckling of the webs. Most usually the two girders of a bridge are joined by riveting to the floor beams, so that all forms a connected system. An angle plate then is set between the floor beams and girders, to prevent the latter from swaying or careening.

But on some roads many of the plate girders have wooden floor beams; the latter sometimes resting directly upon the lower flanges, and sometimes on angle bars riveted to the girders. A neat and serviceable small bridge, where there is sufficient water-way, consists of plate girders, about ten feet apart, with lateral and sway bracings, and upon which are mounted the wooden floor beams. This plan is carried down to I-beam girders of ten feet span or less.

In a few instances weak iron bridges have been strengthened by springing iron arched ribs from the abutments, composed of channel iron, and securing the same to the trusses of a suitable number of points.

At the present day many good iron bridges are found to be too weak. This is due not to any engineering defect, but to the growth in weight of freight loads and rolling stock. We now find sixty-ton locomotives where formerly there were forty; and twenty-ton loads per car where there were ten. Hence bridges designed to a strain of 10,000 pounds per square inch of iron section, as due to the former loads, must now stand 15,000, or perhaps more. This is unfortunate, since an iron bridge is so difficult to strengthen in a satisfactory manner, and so difficult for the road men to get renewed.

Expansion and contraction of iron bridges is provided for in supporting one end on rollers. In short spans, however, rollers are dispensed with, and the bearing plates slide. Often the observed expansion reported by bridge attendants does not account for the whole variation of length, even where rollers are in use. It is believed by some that the rolling resistance under so much weight is so great as to spring the piers

where piers are tall. Thus it appears that strains, due to constrained expansion, may be too great upon chords to be ignored in calculating total strains.

Strains under Maximum Loads.—In proportioning the parts of bridges for resisting their strains, a great variety of detail exists in the present practice. We find no "live" bridge engineer of to-day adopting a fixed maximum load per foot for all spans, even for the same road and the same trains; neither do we find the same fractional part of the ultimate or elastic resistance of the iron adopted for the allowable strain for all parts of any one bridge. The factor of safety is "a thing that was" to such an engineer.

In the first place the quality of the iron is allowed to differ for different parts of bridges. Tension members are never made of anything but "double-refined" iron, that is, iron that has been double rolled. This consists of taking "muck-bars" (the result of first rolling from puddle blooms), cutting and piling them, reheating to a welding heat, rolling into bars, then cutting, piling, and reheating again, when they are rolled to the needed sizes. Compression pieces are single refined, in which the last piling and rolling above described is omitted. Channel bars of columns and upper chords are thus treated.

A fair quality of double refined iron in bars should have a tensile strength of 50,000 pounds per square inch; an elastic limit of 26,000 to 30,000 pounds per square inch; should stretch fifteen per cent. in eight inches; bend 180° around a cylinder of diameter equal its thickness without fracture; and when knicked and broken should show a fibrous structure. Such iron in the regular truss tension members is usually allowed to be strained to 10,000 pounds per square inch for the maximum load. In some cases floor beams are allowed 8,000 pounds only, because they are strained nearly to the maximum allowed for each passage of load. This is true of floor beams, because the greatest load occurs when under the drivers of the locomotive. In the main truss, however, the maximum strains are only reached when the whole train is up to the maximum, a condition which does not happen with every train. The ⊓ shaped hangers for floor beams are usually allowed only 5,000 to 7,000 pounds. Struts and upper chords are computed as columns, and on a supposed basis of about 8,000* pounds square inch. This low value is probably partly due to the fact of single rolling for channel iron.

Assumed Maximum Load.—In calculating the maximum strains there are two ways of treating the question of the maximum load.

1st. By adopting the greatest actual train weights, such as two of the heaviest locomotives, followed by a train of the heaviest loaded freight cars; then computing the strains as static effects to which results are added, for "dynamic effect,"

For spans of about	30	feet.....	25	per cent.
" " "	50	"	15	"
" " "	75	"	10	"
" " "	100	and over...	0	"

2d. By assuming fictitious train weights which are uniform per foot for the span, but which are much the greatest for short spans. Thus, for some roads on this plan, the assumed load for calculating strains is:

For spans of	10	feet.....	6000	lbs.	per foot.
" "	40	"	4000	"	"
" "	150	"	3000	"	"
" "	500	"	2500	"	"

This diminishing scale is to be accounted for as providing, first, for impact; the latter being greatest for short spans, because so much more quickly passed by the forward end of a train, and causing an application of load which is so sudden as to be of the nature of a blow; and, second, because short spans have the locomotive itself for the maximum load, while longer spans can only be covered by adding to the one or two locomotives, some portion of the train.

Crystallization of Iron in Bridges.—As regards the deterioration of iron in use by crystallizing, there are differences of opinion and two few facts. One man will present evidence of crystallization, while another will produce equally good evidence against it. It appears that data are too uncertain. When rods taken from a bridge are found to be crystalline, it is not known whether they were not so when put in. But this matter will be

*By a rational formula for columns, published by the writer since this paper was presented to the Society, it is shown that this value should be but a little over 6000 pounds. (See VAN NOSTRAND'S ENGINEERING MAGAZINE, for June, 1882.)

settled in due time, because positive data now exist as to the condition of iron in existing bridges. When the future engineer shall examine the parts of these bridges, and compare notes with the former records, we shall know how about crystallization.

Steel Bridges.—We are now at the verge of a steel bridge era, several important steel bridges being already built, and in process of construction. The most important mechanical difficulty in this direction is already overcome in the existence of machinery, for the manufacture of solid steel eye bars. Steel is in every way better fitted for bridges than iron. It is less subject to deterioration, becoming more uniform in results of manufacture, has an ultimate strength of nearly double that of iron, and an elastic limit from two to three times as high. Considering the strength, it is but little, if any, more costly. This step from iron to steel is but the natural course from cast-iron up, which latter material is now entirely abandoned as a material for bridges, except for unimportant members, such as wall plates, packing pieces, etc.

Sway Bracing.—In both wood and iron bridges "sway" bracing is universally employed in deck bridges. But such bracing is held in doubt by some, except at the ends of the bridge, where it should be especially strong. The reason given for this belief is that where one truss receives a greater strain than the other from any such cause as wind against the train, train at one side, as in double-track bridges, curved track, etc., the truss should be allowed to remain in a plane. But the sway braces preserve the cross section, so that if one truss deflects more than the other, each truss must careen to one side to some certain corresponding extent at the mid-span, but not at the ends, because here the solid abutments prevent. This forces the chords laterally out of a straight line, causing horizontal transverse strains upon them. The eye bars on one side of the lower chord would, under these circumstances, be strained more than those on the other side, an inequality which would disappear in the absence of sway bracing. Not only would the main trusses be affected, but the lateral bracing at top and bottom would be strained unduly, and probably higher than provided for in the oversight of this matter. The old Ashtabula bridge was an iron deck, and who can say to what extent the sway bracing were responsible in the failure of it?

Though the one consideration of greater flexibility of cross section seems to favor the omission of sway braces, in that we thus obtain freedom from stresses in one system of bracing as due those in another system, yet it is probable that the yielding cross section will allow the train, while under wind pressure, to be forced to a greater inclination toward the leeward, thus causing a probable greater displacement of the center of gravity of train toward the leeward truss, and increasing the strain on the latter.

Vibrations and Strains.—In observing the deportment of a bridge as a swift train passes over, the parts are seen to be much agitated. Tie rods will often fly about at the middle parts to a very considerable extent. This has evidently received some attention by engineers, because in a few instances tie rods at the crossing points have been found tied together apparently to stop vibrations. That all such vibratory movements cause direct strains in the vibrating parts there can be no doubt; and it is unfortunate that these vibrations cannot be predetermined so that the strains resulting from them can be calculated. Could these be accurately determined, it is probable that the practical maximum working stress for bridge iron in tension could be safely raised from 10,000 pounds per square inch to 15,000 pounds; a margin being still left between the latter figure and that for the elastic limit for indeterminate strains due to such movements as considered below.

Lurching of the Bridge.—In some cases the whole central part of the bridge is also in an agitated condition, both vertically and horizontally. There seem to be various causes for this, such as want of perfect balance in the drive wheels and connections, error in perfect alignment of rails, especially in the vertical plane, wandering of the wheels from side to side over the 1″ to 1½″ of clearance between flanges and rails, irregularity of curves on bridges, tangent points on bridges, etc. In some cases this seems to amount to an oscillatory or vibratory movement of the whole bridge.

A Bridge Indicator.—In order to study these effects more satisfactorily, as well as the "dynamic effect" of a moving train upon a bridge, an instrument has been devised which might be called a *bridge indicator*, the object of which is to give a graphic record of the movements of a bridge as a train passes it. A rude affair of the kind has been used with results given below. In this case a bridge near Columbus, Ohio, was chosen as the subject of experiment with the instrument, it being the only one yet experimented with. This particular bridge was a "pony," or "half Howe" truss, of two spans, both upper and lower chords being continuous over the central pier. Each span is 60′ 6″ long, with a total depth of truss of 8′ 9″. The chords are of three timbers, 5″, 10″, and 5″×12″ in section for the lower, and 5″, 10″, and 5″×9″ for the upper chord. Main braces are 6″×8″, and counters 6″×6″.

The upper diagrams of 1, 2, 3, &c., were all taken at the middle of the west span of the bridge. The lower diagrams, of the same numbers, were taken at the middle of the west half of the west span. Thus, any two diagrams under one number were taken simultaneously, the upper at the middle and the lower at the quarter of span.

The track on this bridge was straight, except at the west end, where ten feet belong to a curve of about four degree. Thus, a tangent point lies in about ten feet from the west end. The object of placing an indicator at the west quarter of the bridge was to observe the effect of this tangent point.

A description of the instrument will aid us to a better interpretation of the diagrams. At each point for taking diagrams a wooden board, dressed smooth, was secured to the bridge firmly at one truss. The plane of the board was vertical and perpendicular to the line of the truss. A paper was secured to the board by thumb tacks for each diagram. Upon these sheets while thus tacked to the boards the diagrams were made. At the midspan the paper faced toward the east, while at the west quarter it faced toward the west. From the ground beneath the bridge a stand was built of timbers and brought up to where a pencil could be firmly held by it, and in such position as to lightly touch the paper tacked upon the board secured to the bridge, as above described. Under these conditions a movement due to the yielding of the bridge in any manner would be indicated by a mark of the pencil upon the paper. A vertical deflection of the bridge would make a vertical mark equal in length to the deflection. Also a horizontal movement would be indicated by a horizontal mark, or, finally, any sort of cross motion of the bridge at the indicator would be evinced by its representative mark. In other words, the bridge autographically registers all of its own transverse movements.

The same figures would be obtained, evidently, if the paper were held upon the stand and the pencil upon the bridge, except one would be inverted with respect to the other. The most natural arrangement is the latter, and for that reason the diagrams are so posed that a downward motion of the bridge is indicated by a downward stroke of the pencil on the figure. The figures of the plate are enlarged 2.7 times.

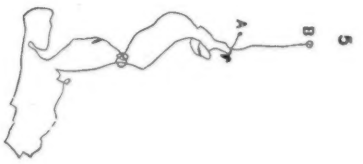
No. 1 was taken at the middle of the bridge when a slowly moving freight

train was passing, drawn by an ordinary-sized locomotive. The pencil was held on the paper till about ten cars had passed going east. The bridge sank gradually from A to C as the engine approached the middle of the span. But as it passed on over, the pencil rose to D, and remained there till about five of the heaviest loaded cars passed. For the lighter cars following, the pencil rose to E and remained there for the next five cars, and it was then removed.

No. 2 is for a freight train going west at about twenty miles per hour. A is the position of the pencil when the bridge is at rest. As the engine came upon the east span the pencil rose from A to the top of the figure, and then descended again to the bottom as the engine came over to the middle of the west

span where the indicator was located. Then the pencil rose to the top of the open part of the figure when it was removed, the engine having just left the bridge. The lower part of No. 2, taken at the quarter, had the pencil in contact longer than the upper part; the heavy blotch at the top of the lower third occurring while the cars of the train were passing.

No. 3 resulted from the passage of a passenger train of four cars going west. As the train struck the east span the pencil rose from A to B, but descended as the engine came upon the west span to the lowest point, it then rose to the heavy markings at the middle. Finally the pencil returned to A.

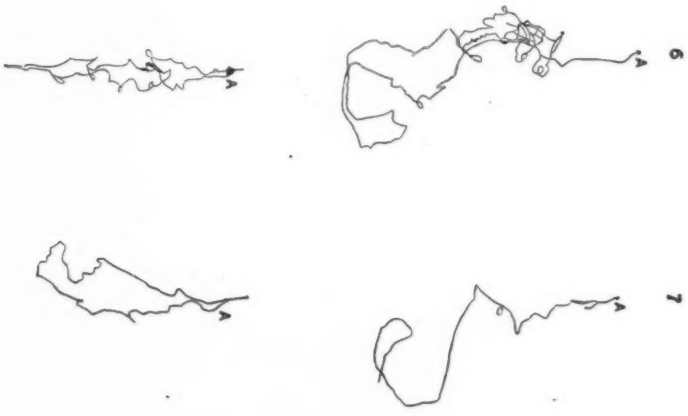


No. 4 is for a passenger train going west. As the engine came upon the east span the pencil left the point of rest A, rose to B while engine was on east span,

went to lower part of figure as engine came on west span, but finally returned exactly to A as the train left the bridge.

No. 5 is for a passenger train going east, four cars. Pencil went down to lower point as the engine was on the west span, then it rose as the second span was reached, and finally went above A to B as the rear of the train was on the east span. But the pencil finally returned to A as the train left the bridge.

No. 6. Passenger train, two cars, going east at about thirty miles per hour. Pencil was removed just as the last car passed it. This explains the absence of the point B. A variety of small movements must have occurred when the pencil was about at the middle of the diagram, thus giving cause for the black blotch.



No. 7 was taken as a pony engine passed very rapidly going east. The pencil was removed as the engine reached the middle of the span. This explains why B is missing. The lower part of No. 7 is a more simple diagram than any of those taken at the quarter, though the pencil was not removed till the engine passed. This is due to the fact that the engine was alone. This card gives us a complete loop, the pencil returning to A.

The diagrams from the quarter point add but little interest. They resemble the others both as regards general form and in having two points A and B. They are smaller than the others, but not so much so as would be naturally supposed. They do not add much light respecting the influence of the tangent point on the west quarter of the bridge. Also the relation of the movements of the bridge at the two points does not appear to be systematic in detail, though bearing a general resemblance as above stated.

Much interest attaching to these diagrams is obscured in the knotted points. To remedy this it is proposed to arrange a clockwork to carry the paper forward, at a predetermined speed, while the diagram is making. Then if the number of cars in the train is noted, and if the instant at which each end of the train passes the indicator is marked by a dot on the moving diagram paper, we will, by knowing the speed of the paper, have data for miles per hour of train, and ordinates for every position of train. But on the paper we should have two curves traced, one for the the vertical movements of the bridge, and one for the horizontal. This would give us the means of completely analyzing the obscure parts of the diagrams.

Simple lurches would be indicated by irregular sinuosities without law, while for vibrations they would be systematic.

One drawback to the general applicability of this instrument would be found in the inconvenience in erecting the tower for carrying the pencils. As a substitute for the tower, it is proposed to throw out a stone anchor from the desired point of application to the bridge, the anchor hav-

ing attached a hempen cord or fine wire long enough to extend up to the point of observation. A pencil is then to be arranged in a slide working freely in vertical guides, to which slide the wire is to be attached. A spring, quite flexible, is then to draw up on the slide making the wire below tense. Then as the bridge rises or falls the wire causes the slide to remain at a constant height, while the instrument and paper are vibrating with the bridge. It is then only necessary to place the pencil to the paper, and the clockwork in motion, to secure the diagram for the vertical movements.

The lateral movements are not quite so easily provided for since there is need of an anchorage at one side on a level. It is believed, however, that this can be secured in effect by two anchors and chords, the latter forming a junction at the horizontally opposite point desired. To hold them, a tension stand under spring action, drawing as a resultant force to the two anchor chords, will fix the junction point as desired. In case of such double anchorage to the lateral and vertical, two pencils may be made to write on the one sheet or ribbon, and thus one clockwork answer the purposes fully.

Such an instrument with conveniences for anchorage could be applied to a bridge in a few minutes, and inspectors could obtain an autographic record of the degree of agitation of any and all bridges examined.

Such diagrams would evidently throw much light upon the vibratory effects due to unbalanced locomotive drivers, and indicate whether cumulative impulses from such parts of the train ever cause dangerous vibrations of whole structures.

Indicated Dynamic Effect.—The diagrams presented are not sufficient in themselves to serve this purpose fully and satisfactorily. Their appearance might, however, suggest some amount of vibration or oscillation. Referring to No. 7, first part, remembering that the pencil was removed as soon as the engine reached the midspan, we observe some evidence of lateral vibration as occurring simultaneously with the sinking of the bridge. But as to the vertical movements, we see almost no trace of repetition of any part of the movement as would be likely to occur if the bridge vibrated in going down, except, perhaps, in a slight degree in the loop in the bottom. This loop is about one-eighth of the depth of the diagram. The lower part of No. 7 indicates almost no vertical vibration in any part. Loops at the bottom of Nos. 6, 5, and 4, indicate vertical vibration, also of about 22, 14, and 10 per cent. of the depth of the diagrams respectively. Taking a half of these amplitudes as the increase of deflection due to dynamic effect, and comparing with the diagrams diminished by the same, we obtain the percentage which the dynamic is of the static effect, as 7, 12, 8, and 6 per cent. respectively, as due to the above measurements. Some of the lower diagrams give evidence of about the same percentages. The mean of these percentages is only about half what is required by some railway companies to be allowed for spans of the same length, viz., 60 feet. As given above in speaking of usual practice in this matter, it is about 15 per cent. for 60 feet spans. But it is always necessary to provide not for average, but maximum stresses in such cases. Hence the maximum 12, is close enough upon the 15 of practice.

Nos. 1 and 2 are both from freight trains, and give evidence of almost no vertical vibration. Also the total deflections, counting from the points of rest A, are less for the freight trains than the passenger trains in Nos. 3 to 6. If, however, we add the above twelve percentage of dynamic effect to the deflection in Nos. 1 and 2, we obtain very nearly the same strains as are actually due to passenger trains ; and singular enough, as obtained in actual practice by computing static effect of freight trains and adding the stated percentage for dynamic effect.

These facts, though corroborative of the real existence of dynamic action or impact, yet at the same time they testify to a somewhat excessive allowance for it by practical engineers. But before drawing conclusions in this way for guiding us in practice, it is necessary that much more extensive data be procured and worked up.

As regards lateral vibration, the first two numbers on the plate are narrower than the rest, the same being taken from

passing freight trains. The others are for passenger trains, except the last one from a rapidly moving pony engine. Hence it appears that fast trains cause much the greatest lateral disturbance. The resulting effect upon the lateral bracing is a matter of interest. By measurement of the widths of the diagrams taken at the midspan, it is found that the total lateral movement for passenger trains is 42 per cent. in excess of the like movement for freight trains. May not this call for careful attention to the subject of dynamic effect upon lateral bracing?

Testing and Selecting Material.—In the selection of material for bridges, great care is exercised by bridge companies, much greater, indeed, than is usually supposed by the mass of people who ride over their bridges. Some bridge companies make tests of the materials not specified or required by the railway companies ordering. For instance, the Detroit Bridge Company examines all the eyebars for a bridge by piling a quantity of them and passing the pin through the eyes at opposite ends simultaneously. Any bar preventing the passage of a pin is thrown out. Then the bars are individually tested to a tensile strain of 15,000 pounds per square inch, and again the pins must similarly pass. If any eyebar has stretched so as to prevent the passage of the pin it is rejected. Such a practice would discover hidden flaws, and would pay if discovering such flaws only at the rate of one in a hundred bridges. A flaw which would probably have been made known by such a test was actually discovered by the road master of the Baltimore & Ohio Railway in one of his iron bridges, and the piece had to be removed. A first-class catastrophe might have here resulted except for the keen eye of the road master. There are those who object to straining iron going into a structure, especially beyond the working load. But a test which will discover the few hidden flaws that would otherwise pass unobserved, will probably more than offset imaginary evils due to strains which, though within safe limits, are somewhat in excess of the adopted working load. Accordingly, this test is believed to be a most excellent one, but of the few bridge companies conferred with in regard to it by the writer, it has been found in use only in the one instance named.

All companies do more or less testing with testing machines, including pieces ranging from small "test specimens" to full-sized bridge members. Tests for tensile resistance are by far more plentiful than compressive, but a good number of the latter are on record including full-sized bridge columns. It is a quite common practice, however, to test a piece taken from a large bar rather than the whole bar itself. Large bars are thus found to have a lower tensile strength than smaller rolled bars.

Testing-machine tests for tension, to meet the present demands of bridge builders and companies, must make known at least three quantities:

1st. The elastic limit.

2d. The ultimate strength.

3d. The percentage of total elongation of some specified portion of the original bar—usually about eight inches.

In some cases the greatest reduction of section is noted, and by some this item is preferred to the percentage as above.

As regards the elastic limit, it is found not to be perfect, that is to say, some permanent elongation is always experienced by good iron before arriving at what is usually adopted for that limit. But practically these elongations are nearly proportional to the increments of load, and extend nearly through the whole range of loading up to the so-called elastic limit. Beyond this limit, however, they rapidly increase. The point where this change takes place is noted as the elastic limit. This limit, thus found, is given a more rational showing from the fact that, if at any point within it, the strain be relieved and then restored, no further permanent elongation is experienced till after passing the previous condition of strain. At points beyond the elastic limit, however, this is not the case. An extended examination of iron specimens will verify the following facts:

1st. Bars immediately from the rolls, which have not been subjected to jars or other causes of strain, will experience permanent elongation at very slight tension. This is true also of bars direct from the annealing oven, even though they had previously been subjected to violent mechanical action. In these cases

there appears to be no limit of perfect elasticity.

2d. A gradually applied and removed tension within the usually accepted elastic limit produces a permanent elongation, which will not be increased for like or less tensions as above stated. This is also true of compression.

3d. A specimen which has been strained, as indicated in 2d, will take a permanent set for a slight reversal of the strain.

4th. At the point where the permanent elongations cease to be nearly proportional to the increments of load, or to the elastic elongations, we find the usually accepted elastic limit. Some of these facts can be verified by simply straining a piece of annealed wire by hand.

But the most common tests in use among bridge builders, and which are at once both invaluable and fortunately of easy application by any blacksmith, consists,

1st, of bending a bar 180° degrees around a cylinder whose diameter equals the thickness of the bar, and which the bar must stand without fracture to be accepted;

2d, of nicking a bar on one side with a cold chisel, and bending it similarly as in 1st, with the nick at the bow of the bend, when it will usually break, showing a fracture which must be fibrous and free from glistening points or faces. Very frequent use is made of these tests in the smiths' workshops where waste pieces of bar ends, which have no other value except for scrap, are put to a most valuable service.

Heads of Eyebars.—In the manufacture of one very important part of iron bridges, viz., the eyebars, a number of methods are in use. One consists of forming the heads by a separate operation, and then welding them upon the bars. The weld is made close to the head without upsetting the bar near the the welding point. This must certainly reduce the sectional area of the bar at points so near the weld as to be heated but not worked, because the heat cannot be taken without corroding the iron, and thus eating away a small portion. But where full-sized bars of this kind have been tested to destruction, it appears that the rupturing point is always at some intermediate part of the bar considerably removed from the head, thus proving the reduction by burning to be unprejudicial. This practical ignoring of the slightly reduced end sections appears to be due to the influence of the enlargement of this head. This conclusion is verified by experiments in tension on extended necks of wrought iron, the fracture always occurring at some intermediate point in the neck.

In other cases heads are formed on the bars by welding several thicknesses of iron upon the side of the bar, thus giving a sufficient body of metal to form the eye. The reduction of section, above mentioned, by fire corrosion will take place here also, but actual experiment has shown it to be without objection, for reasons above given.

Stone Arches.—Of stone bridges there are some fine ones in the State, particularly on the Lake Shore & Michigan Southern Railway, the Baltimore & Ohio, and the Cincinnati, Cleveland, Columbus & Indianapolis. The former has four or five large stone-arch bridges, two or three of which are two span, and they run from 40 to 80 feet diameter. Also one beautiful two-span skew arch of about twenty feet diameter. At Bellaire, the Baltimore and Ohio Railway has a remarkably fine stone viaduct, consisting of thirty-seven semicircular arches of 28 feet diameter, supported on piers 6×12 feet. The height of the copings above the streets of Bellaire is 32 feet. Twenty of these arches are in a straight line, and seventeen on a four-degree curve, all in dressed stone.

Stone Quarries.—In the selection of stone from Ohio quarries for important structures, care is needed lest a soft stone be taken which will not stand the weather.

The Roadway.—Ordinary railroad lines consist of four parts, viz., *bed*, *ballast*, *ties* and *rails*. A cross section of the most perfect roadway found in Ohio

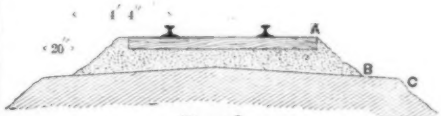


Figure 2.

is given in Fig. 2. The Pittsburgh, Fort Wayne & Chicago Railway has some

seventy miles of it, so fine in its outlines as to be truly a work of art. It is, indeed, unfortunate, that all passengers cannot conveniently see it from the moving car. Observed from the rear car of a train, it appears like a beautiful striped ribbon stretching away in the distance. Across the top the stone ballast is just to the upper surface of the ties. At A a definite line of intersection is formed. At B is another, and also at C. The slope, AB, is as perfect as though the ballast had been piled under a board. The limit of ballast at B is by a single row of ballast stone between egg and nut size, and individually laid by hand. The upper surface of the bed is crowned or convex, as shown in the figure. The part, BC, is all patted smooth with shovels. A weed is not allowed. The ballast is broken stone where this form of bed is found. The road, however, has not all stone ballast, though the amount is increasing from year to year.

Other roads have considerable portions laid with stone ballast, that ballast being much sought after. Cinder or slag from furnaces is also employed, it being preferred to some kinds of stone.

Some Ohio Stone is entirely unfit for stone ballast, and does not pay for hauling it from positions of convenient proximity. It pulverizes in use. Limestone is said to be the preferable stone. In considering what material shall be declared the best ballast, it appears that a best ideal ballast must be heavy enough to not be easily disturbed when laid, and to hold the ties in ballast; it should not be too fine nor too coarse, say about egg size; it should have sharp angular corners to hold the ties, and it should be impervious to water, so as to dry out quickly for preservation of ties. Probably the best possible material for uniting all these conditions is broken glass. It weighs about the same as limestone. Glassy furnace slag comes very near to it. Sandstone is the poorest of all stone, since it wears rapidly so as not to hold the ties, and it absorbs moisture, and holds it to the rapid decay of the ties. But impervious stone allows rainwater to run directly through the ballast to the bed by trickling down the surface of the fragments and without absorption. On reaching the bed it flows off to the right and left, if the bed is sufficiently crowned at its summit. In the best practice it is actually crowned for this purpose.

The minimum depth of ballast shown in Fig. 2 is six to eight inches under the ties. It often actually exceeds this, sometimes to the depth of several feet. Two reasons are given for this, first, a new bed settles causing inequalities of grade; and, second, inequalities of grade admitted in new roads are, to a considerable extent, equalized according to growing importance of road. In these cases, rather than add new bed material to revive settling annoyances, ballast is piled on.

Ties.—Ties used in the State are mostly oak; the best being obtained from Virginia, and known as "Virginia ties." They are of white oak and run from 10″ to 12″ width. Chemically treated ties of elm and some other woods have been used to some extent. The number per mile varies between 2500 and 2800.

Slip Sides.—In a few instances "slip sides" have been encountered in which the whole fill, or embankment for a length of one or two hundred feet, will gradually be carried laterally out of place. These are found very difficult to manage. In one case, on the Baltimore and Ohio Railway, a filling of coal slack was used after several editions of earth filling had been carried away. The coal stood very well, its less specific gravity being supposed to be the cause. In some cases piles are driven, the idea being to "pin" the slipping bank to place. But these pins often get badly demoralized from the great pressure. Springs of water are usually found along the upper limits of these slipping sides.

The Track Line.—The alignment of the track on curves often gets deranged to a surprising extent; in one case over forty per cent. by measurement was the degree of curvature raised. One instance, on the New York, Pennsylvania and Ohio Railway was noted where a curve carried the train badly. Several unsuccessful attempts were made to correct it by throwing the track by eye. Finally the curve was re-run with instruments and found badly out. In many cases the track has been observed to be appreciably deranged where measurements were not taken.

Such derangement occurs by the work-

ing of section men on the road, as in re-adjusting grade, or outer rail elevation; in placing new ties, rails, etc. Tangent points undoubtedly "creep" from this cause, the presence of them a few feet in upon bridges, as noticed in a few instances, being apparently due to it.

Track men should have some easy and simple means of ascertaining the deformity of curves and the proper "elevation of the outer rail." For the latter an extraordinarily simple and efficient device was found in force on several roads, viz.: a cord or string of certain length, say 60 feet, and a rod; the former being stretched as a cord to the curve, the versed sine, measured on the rod, is the elevation of outer rail. Some use 63 feet, and others less for the cord length. For the 63 feet the elevation is right for about a 36-mile speed.

In this device we find the suggestion for a curve corrector, viz.: at all points of an ordinary curve the versed-sine, for the 63 feet cord, should be of constant value.

In regard to the tangency of straight and curved portions of track, the usual practice is to make the curves true circle arcs, and exactly tangent to the straight parts. A little consideration, however, will show that instead of this, the path described by the center of gravity of a car should preferably have its corresponding parts thus in true tangency. But this cannot be where the outer rail is elevated or inner one depressed, or both, because in tilting the car for this difference of rail elevation the center of gravity is thrown in, and passes around the curve on a circle arc several inches within the circle which is truly tangent to the straight parts of the path. This has the effect to give a jolt to the car on entering on a curve. But, in practice, this is compensated in a measure by commencing the elevation of rail on the tangent itself at some distance from the tangent point, and bringing it up to the full value at or near the tangent point.

The object of making a difference of rail elevation on curves is to make the resultant of gravity and of centrifugal force take a position which shall be normal to the floor of the car. To secure this result perfectly, in every respect, it is evident that we can neither begin the elevation on the tangent nor admit of anything less than full value on the initial part of the circular curve. Neither should there be any offset, sudden or gradual, in the path described by the center of gravity of the car, such as above mentioned as due to rail elevation. Abrupt disturbances in the direction of this resultant would be perceived as jolts toward one side or the other. It is evident that the direction of a disturbance which would be least noticeable to a passenger, or have the least tendency to derail a train, would be vertical, and hence this is the most admissible. But it appears impossible to preserve quietude in every respect in a car, even though the resultant force above named could be maintained truly in the normal position indicated, because the car must be rotated on some longitudinal axis to the extent of the difference of rail elevation. This necessitates an elevation of one side of the car, depression of the other, or a compromise action, the latter being probably preferable. Hence one rail must be depressed as well as the other elevated, the best condition being obtained when the center of gravity of the car is neither raised nor lowered.

Under these conditions, viz.: first, maintenance of perfectly normal resultant; and, second, a slight rotative movement of the car on its longitudinal axis, we secure the least possible disturbance. Then the only sensation to a passenger, if indeed any be possible in going round a curve at the proper speed, would be that of slight lifting or lowering, as depending on sitting at the lifted or lowered side of the car.

But it is clearly not possible to realize these conditions when a straight track is, according to custom, changed abruptly to a circle. Not even though the circular curve and tangent belong to the center of gravity of the car, instead of the middle line of track. The only way to fulfill the conditions indicated appears to be, to gradually increase the curvature from the tangent to the circle by an intermediate curve of varying curvature. This we will term an *easement** curve; the main circular curve beyond the easement curve being called the principal curve.

* Called curves of "*easing changes of curvature*," and "*curves of adjustment*," by Rankine; also "*spiral curves*," by others. See *Rankine's Civ. Eng.*, p. 651; *Railroad Gazette*, Dec. 3d, 1880; recent articles in *The Engineering News*, etc.

Now the easement curve must, throughout its length, maintain perfect continuity of proper relation of the radius of curvature and rail elevation. That is to say, to meet the above conditions, the radius of the easement curve must change from point to point; and the rail elevation at any one point must be precisely that required for the radius at that point. This relation of elevation and radius is well known, viz: the elevation is simply in the inverse ratio of the radius. Or, again, the product of the elevation and radius of curvature is a constant for any given number of miles per hour for speed of train. This is true whatever the form of easement curve, and hence the latter is neither determined nor influenced by that relation.

Being free to assume the law of the easement curve, it appears that the very best conditions possible to adopt for fixing it are to assume, first, that the car, in tiltng to the difference of rail elevation as it passes along the easement curve, shall rotate about a longitudinal axis passing through the center of gravity of its cross section, and, second, that it be accelerated in that tilting movement, so that a passenger at the side of the car shall experience only the sensation of a slight change in his own weight while on the easement curve. That change of weight will be an increase if outside and going from the tangent, and *vice versa*. This change of weight, however, should be made imperceptible, and it is believed so to be when arranged as below.

This makes the law relating to the time and rail elevation identical with that of falling bodies, or with

$$h=\tfrac{1}{2}ft^2$$

where h is the elevation, f the constant acceleration, and t the time. Now suppose that in running this easement curve, 50 feet chords are adopted $=c$.

Let the number of chords reckoned from the tangent point $=n$. Also assume that at 400 feet from the tangent point the elevation of one rail over the other be 12.8 inches. Let the number of chords passed per second by a passing train be $t=nc$. Substituting these values and reducing for a velocity of 30 miles per hour, we obtain

$$h=0.2\,n^2$$

From this we obtain for

n =	1	2	3	4	5	6	7	8
h =	.1″	.8″	1.8″	3.2″	5.0″	7.2″	9.8″	12.8″
R =	17190	4297	1410	1074	68.8	478	351	126

n being the number of 50 feet chord lengths from the tangent point, R the radius of curvature, and h the difference of rail elevation in inches, for a track gauge of 4′ 8½″.

For a speed of 45 miles per hour, for the same radii, R:

n =	1	2	3	4	5	6	7	8
h =	.36	1.4	3.2	5.7	9.0	12.8	15.4	22.8

It is observed that the radii are the same for all cases. This makes the easement curve the same curve for all speeds, the allowance for different speeds being made in the elevation. Hence the curve can be laid out from the same set of deflection angles, computed once for all.

In a particular case of practice, the easement curve is to be continued to where the radius equals that of the *principal*, or main circular curve; when the latter is to be run tangent to it in continuation.

Now these curves should be understood as forming the proper path for the center of gravity of the car, and not the center line of the track. For greater convenience to passengers, however, it should be the path to the center of gravity of the load of passengers. But as these centers do not differ much in position, they may be assumed coincident.

Assuming this center of gravity to be at a height above the track equal to the gauge of track, viz., 4′ 8½″ usually, it appears that in order to make the path of that center of gravity describe the easement and principal curves above laid down, it will be necessary that the curves, when first laid out on the ground, must be moved outward at each point a distance which just equals the difference in rail elevation, h, at that point. This is to provide against displacing the center of gravity as the car tilts to the difference of rail elevation.

Hence, in practice, run the easement curve as above, till its curvature equals that of the principal curve. Then set out each point the amount h proper to it as rail elevation. Then continue on the principal curve. In laying the track depress the inner rail, the same amount that the outer one is elevated, both to-

gether being h. This is to be done for that speed of trains at which it is desirable to have the most perfect freedom from all manner of disturbances.

In compound curves not reversed, the easement curve should be introduced to give a gradual change of curvature, rail elevation, &c., from one curve to the other. In reversed compound curves, the easement curve and elevations should be used to change from the first principal curve to where the track would run off on a straight tangent, and then it is to be run, in the inverse order, to where its curvature equals that of the second principal curve, &c. In short, every portion of principal circular curve should begin and end in an easement curve, as described above.

This gives perfect freedom from side jolts and a probably imperceptible vertical lift or decadence. To give an idea of the latter effect, that is to say, of the apparent gain or loss of weight, suppose a man of 200 pounds weight to be at the extreme side of a car, and that the car enters upon the above easement curve at 30 miles per hour. The accelerative lifting or depressing force due to the 200 pounds weight will be, by calculation, only 0.16 of a pound, or about $2\frac{1}{2}$ ounces, an effect which would influence the cushion of the car seat less than to place an orange in the rider's lap.

But all the above refinements respecting the alignment in the horizontal plane will be of but little avail where the importance of the vertical alignment is ignored. From an extended examination of track, both by sightings from the ground, and by taking advantage of opportunities of riding miles within one or two hundred feet of a second track, and of allowing the two lines of rail to spin through a fixed gaze with a view to observing the relative heights of the two rail lines, it is believed that the error of vertical alignment is usually at least five-fold greater than in the horizontal.

Of two sections of road, if one should be found as badly out in the horizontal alignment as the other in the vertical, each otherwise correct, it is altogether probable that the section boss of the former would get his discharge the first time the road master came along, while the other would very likely be commended. But in this case the wrong man is discharged, because, as to the riding qualities of the two sections of track, the former would be far the best. This fact is evident by observing that the weight of the car is sure to cause it to follow all inequalities in the vertical alignment, while most of the lateral deviations of the rail will be skipped, and pass without effect. But even if followed to detail, in both instances, the vertical deviations will rock and tilt the car badly, and cause disturbances which will be magnified by the height of passengers or freight above the track. To explain, suppose one rail perfect in line, and the other to rise and fall one inch, in distance of fifty or a hundred feet. Here one wheel has a latitude of vertical movement of one inch. The straight rail forms an axis to this motion, and if a circular cylinder, of radius equal the track gauge, be drawn to this axis, cutting the car lengthwise, every point in that cylinder would have the one inch of motion. That is, a point vertically over the straight rail, at the height of track gauge, would move sidewise one inch when the wheel on the opposite rail rises and falls one inch. Persons in seats directly over the straight rail receive the lateral jolts of about one inch. But persons in the seats at the opposite side of car receive jolts which are both vertical and lateral to the extent of about one inch, which amounts to a diagonal jolt of about one and a half inches. The top of the car may, at the same time, be thrown two or three inches.

This supposes one rail straight, but it is as likely to be cut as the other; both sometimes together and sometimes opposite. In case both rise together one inch, the car receives the vertical displacement bodily of one inch.

But when they are in discord, the passengers are thrown to an extent nearly double that due to the single rail error above. The consequent jolting annoyance cannot safely be prevented by rigid car-couplings, because the strains would be great upon the couplings, and no coupling attempts it.

But now suppose equal inequalities in the lateral direction or in the horizontal alignment. The wheels would skip most of them, the tendency being to go nearly straight ahead rather than turn out for all side-crooks in the

rails. This is rendered possible by the clearance between the wheel flanges and rails. The cars are prevented, to a great extent, from wandering from side to side of the clearance by use of couplings, which offer a considerable resistance to the lateral movement of one car end, crosswise to the one coupled to it.

From these facts it appears that the vertical alignment is the one which demands the most careful attention for exactitude, while in practice it seems to receive the least.

"Low joints" are found everywhere, though in the most carefully guarded track they are slight. Where the "fish plates" are allowed to get loosened, the wheel pressure and peneing action bend the rails to an arched form. Small "joint ties" also favor low joints.

If the rail joint could be given the same stiffness as the body of the rail, and then if the bearing of the ties upon the ballast could be uniform along the rail line, the rails would remain straight. The "angle bar" is superior to the fish plate for making a stiff joint; but as no joint in use is as strong as the body of the rail, it follows that the deficiency should be made up by a greater amount of tie bearing near the joint. There are many advantages in the so-called "suspension joint." It is formed by placing the abutting ends of the rails over a space of about ten or twelve inches between two ties, so that the fish plate or angle bar will span the space, and be secured upon the ties. The advantage of this in the matter of low joints consists in the greater amount of tie bearing upon the ballast at the locality of the joint, and due to the fact that these two ties are nearer each other than other ties along the rail. But still the tendency is to low joints, and it seems necessary that, in laying ties, the two widest ones be selected for the pair at the suspension joints. This, together with closely-fitting angle bars, it is believed will maintain freedom from low joints. This is based upon the supposition that the ties along the middle portion of the rail be all smaller than the joint ties.

But, in actual practice the joints in one line of rails are sometimes placed opposite those in the other line, and sometimes the joints alternate. Some road masters strenuously insist on opposite joints, others equally so on alternate, and each will have no other. This is the one thing about railroads on which there is found the greatest prevailing difference of fixed opinion.

Now, respecting the bearing of the joint ties upon the ballast, 1st, when the joints are opposite, we find that the selected wide ties, which become joint ties for one rail line, are also in proper position to serve as joint ties for the other line. This also leaves the middle portions of the rails resting on the smaller ties, a condition pointed out above, as favorable for preventing low joints. But when the joints are alternate, the wide ties selected must be twice as numerous, and consequently differing less from the remaining ones; but besides this we find that the wide ties for the joint at one side extend across, and become wide ties at the middle of the opposite rails. This favors low joints, as pointed out above, and is one reason why alternate joints should be avoided.

But some contend that alternate joints ride more easily and pleasantly than opposite. This is probably true for equal degrees of low joints, but it seems to be an open question whether the alternate joints, with their greater tendency to low joints, will carry trains more smoothly than will opposite joints well laid on the selected joint ties. But on some roads very little if any attention is paid to selecting joint ties. In such case it is probable that alternate joints will ride smoothest.

It might be supposed that alternating low joints would give an oscillating motion of car from side to side, and opposite joints a vertical oscillation. The latter is likely to occur for speeds under about twenty-five miles per hour. But in high speeds the time between joints is too small for serving as a period of vibration or oscillation. Hence it cannot take place. At thirty miles per hour, alternate low joints appear to be entirely without effect for all oscillation, and is not noticed at even twenty or perhaps fifteen miles per hour.

From these facts it appears that low joints can be more effectually avoided when opposite, but will have less prejudicial riding qualities when alternate.

Rail Sections and Weights.—The form of rail section is a matter of consid-

erable import. The prevailing modern form is nearly like No. 1, Fig. 2*a*, while some of the older rails in use in the State are nearly like No. 2. Various devices have been used for making the

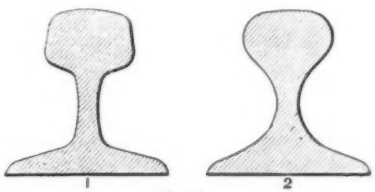


Fig. 2 *a*

joint in No. 2, but it is a hard rail to hold. Fish plates and bolts soon release their grip. The bolts are apt to break, but they first stretch and loosen the plates. Then the plates, rails, and bolts wear badly, because the form of section is seen to not be favorable for holding a fish plate. On the other hand, the upper and lower parts appear much as though they would serve admirably as wedges to spread the fish plates and tear the bolts. In some cases wood is used on one side, and sometimes both wood and iron.

But the nearly square shoulders between the head and foot in No. 1, are seen to be especially well adapted to hold a fish plate. Even a little looseness under the fish-plate bolts would not admit of very much vertical displacement of one rail on the other at the abutting ends.

Rail weights vary on Ohio roads from 50 to 67 pounds per yard, the most common being 60. It is often the case that heavier rails are laid on curves than on tangents. This is to provide against the greater wear on curves.

Lock Nuts.—In spite of the fact of numerous existing lock nuts of merit, none seem to meet all the requirements for fish-plate bolts. The simplest found in use is the Verona lock nut. It consists of a split and offset ring of steel, tempered to a spring, and having cutting points at the split. It appears to be made of quarter-inch square steel, cut and bent nearly to a ring, but having an offset of about one-eighth inch, where the ends nearly meet to form the ring shape.

Wear of Rails.—Practice develops the fact that the outside rail on curves becomes by far the most worn. In some cases the outside worn rails, and inside nearly perfect ones, are interchanged, so that each shall get its portion of wear. The wear now referred to is mostly on the side of the rail head. The tops of the heads also become much worn. Altogether the wear on curves is much in excess of that on tangents, a fact which accounts for laying heavier rails on curves.

The fine theory of the "coning of wheels" is entirely without force in practice. Wheels wear most near the flanges, so that in a short time the effective coning is reversed; that is, the wheels become smaller in diameter of tread at points near the flange than at points remote from it. It seems evident that the more wheels become thus worn and lose their coning, the greater will be their tendency to climb outward on curves, and consequently the greater will be their slip and the greater the wear, not only of wheels, but also of the rails on curves.

The recent improvement in chilled car wheels of leaving an inch at the flange edge of tread, without chill, will doubtless tend to make the wear more uniform over the whole tread.

Switches and Frogs.—A great variety of notions about switches and frogs are found in vogue. For instance, some have decided preferences for the Lorenz switch, and others for the Wharton, where any other than the ordinary plain switch is desired.

The Wharton switch is the homeliest switch, probably, that was ever made. It would never get adopted from any good looks. But it has great advantages for certain positions in track. A remarkable property of it consists in its leaving the main line of track entirely intact or unbroken. This is secured by means of parts so formed and raised as to lift the wheels high enough to carry the flanges over the rails at the one side. In practice, both sides are raised. This raises the cars also in passing the switch, a requirement which could not be admitted at high speeds of train.

Hence it appears that this switch is especially adapted to places where trains are to pass at high speed along the main line, but where it is necessary to occa-

sionally turn out to a side track, the latter being always at a reduced speed. Being a "safety" switch, it is well adapted for yards and all places of much switching at slow speeds. While the Wharton switch requires one sharpened rail, the Lorenz requires two. These are so fitted that they will lie close up to a whole rail, and receive a wheel from it. The Lorenz admits of two unbroken lines of rail, but one of them turns off to the branch track, so that one rail of the main line is cut. In this rail it becomes unnecessary to raise the cars in switching. Hence this switch is adapted to location where a train may continue on main line or take a branch at speed. This switch is made a safety switch by introducing a spring. But the spring is seriously objected to by some, with the statement that a stick or pebble may become engaged between the pointed and fixed rail, and thus throw a a train. Devices have been introduced for obviating this objection.

Beside the ordinary "frog," two others are found in use, viz.: the spring frog, and the self-acting frog. Some roads are very partial to one or the other of the two latter, while others will have nothing to do with them. The chief objection seems to be that the movements are apt to become obstructed by sticks, dirt, cinder, snow or freezing, &c. But on main lines, where turnouts are to be passed at speed, and on lines passing fifty to a hundred trains per day, a common frog is apt to become much worn in a comparatively short time. The spring and the self-acting frogs have far greater wearing qualities than the common frog, because they secure nearly the effect of an unbroken rail. Where switching is not frequent, and trains pass at speed, the Wharton switch and spring frog are good accompaniments.

Bridges on New Roads.—Economy in the management of railway structures favors the adoption of cheap wooden ones, such as trestles, pile bridges, &c., in the construction of roads, the same to be renewed in due time by more permanent ones. One important consideration in regard to this is the practical "waterway" under bridges. In some cases trestles, a few hundred feet in length, have been introduced at points of unknown water way, which have subsequently been reduced to a complete fill, with the exception of a tile opening. In other cases iron structures have been undermined by reason of a cramped water way.

The life of a wooden bridge is, perhaps, none too long for enabling the engineer to learn the actual demand upon any bridge location for the water way. In one instance, a fine Pratt truss of over one hundred feet span was placed over a nearly dry channel, at a height above bed of only about five feet. A stranger to the locality would wonder why the space was not filled with dirt, at a cost of almost nothing comparatively. But should he happen to be along at the one or two times a year when water was up, he would form an opinion, sound and correct, as to water way.

Cattle Guards.—This structure, though of seeming insignificance, is yet of very great practical moment. This is due to two facts, viz.: first, the great number of them required on a single road; and, second, that any one defective cattle guard is sufficient to wreck a train.

The amount of attention given to this matter by different roads varies greatly. For instance, they have been found built, except the "strings," of ordinary rail ties, and without much designing either. Some roads have an almost infinite variety, and most of them being built of such material and in such manner as is most convenient to the locality. Others will not only have a carefully designed and specified "standard cattle guard," for universal use, but will have material lying in their material yards all along the road, cut to specifications and ready for setting new guards, or for repair of old ones, on the plan of interchangeable parts.

The latter system reduces the matter of cattle guards to a basis of manufacture, with all its advantages of economy, stock on hand, &c.

The three most characteristic standard cattle guards, observed by the writer in the tours of inspection, are here described.

The standard of the Pittsburgh, Fort Wayne & Chicago Railway, shown in Fig. 3. A pit is first sunk nearly three feet deep, filled nearly one foot with broken stone. Then two square timbers, about $12'' \times 12'' \times 12'$ are laid crosswise the

track at each side of the pit, and resting on the stone. On these, against the pit's banks, are laid, on edge, planks about 3″ × 12″ × 12′. Between these planks the "strings," about 12″ × 12″ × 6 or 8′,

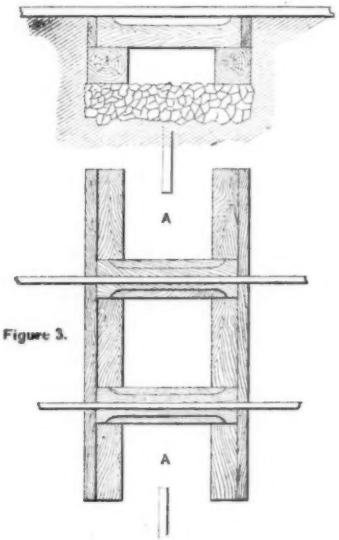


Figure 3.

are placed one under each rail, as shown. The planks are heavily spiked to the strings, thus fixing the distance between the latter. The rails are spiked directly to these strings, the latter being chamfered. The fence, on either side, terminates about at A, as shown. An effort is always made to drain the pit by a channel, so that water scarcely ever lies about the pit timbers or mudsills.

In this guard the pit is generally left open, and is about two feet deep. Slats are sometimes put on, though this seems to be the exception.

The standard of the Cleveland, Tuscarawas Valley and Wheeling Railway is shown in Fig. 4. Two sticks, about 12″ ×12″×12′ are placed in the bottom of the pit, 8, out to out, crossing the rail line. On these are placed two sticks or strings, about 12″×12″×8′, one under each rail. On these last are placed 5 sawed ties 6″×7″ or 8″×8′ and notched on to a remaining depth of 6″. The outer ties are placed flush with the ends of the sticks on which they are notched. Against the outsides of the outer ties, and extending down by, partly over the ends of the strings, are placed planks about 3″×12″×12′ and spiked. Across the ends of the ties a binder or guard rail of wood is bolted. The rails are

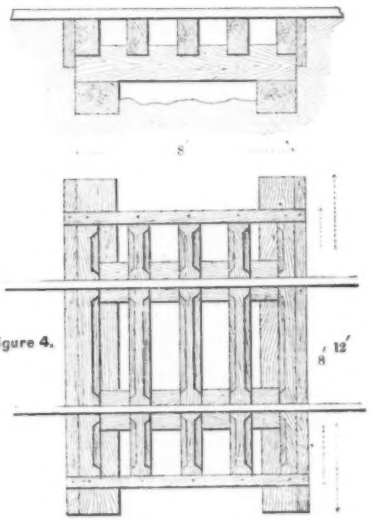


Figure 4.

spiked upon these ties as on any other ties. The upper corners of the ties are chamfered.

This is believed to be a most efficient guard. Its cost, as compared with that of Fig. 3, depends mainly on whether the five sawed and chamfered ties, and guard rails and boats, of Fig. 4, cost more or less than the stone filling in the bottom of Fig. 3.

The Baltimore and Ohio Railway have a more elaborate and costly standard, shown in Fig. 5. In the bottom of a pit three mudsills are placed, each about 12″ ×12″+12′. Across and on these are laid the string pieces, one under each rail, and 12′×12″×8′. The ends of these are notched into 5″×12″×12′ planks, the outsides of the latter coming just flush with the two outside mudsills. The strings are chamfered, and the rails are spiked to them.

Slats or bars are counted an essential part of their guard, and they are provided for in a most ingenious manner. On the inside of each of the outer heavy

5″×12″ planks is spiked a 1½″×8″×12′ plank, notched at spaces of about 12″. The notches are diagonal, so as to carry 4″×4″ bars lying in a diagonal position, that is, so that one corner of each stick

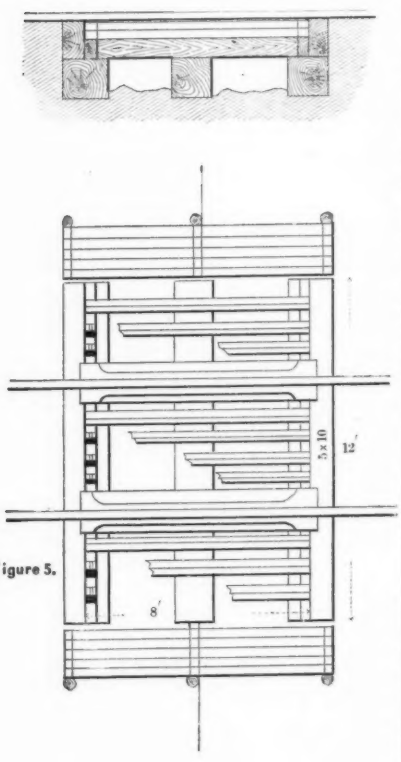


Figure 5.

is up. These bars are not nailed, because in a few months they sag, and are then turned over. As often as any one sags it is reversed.

At each side of the track, or end of the guard, is placed a half length of fence as shown, from which starts out the division fence to which the cattle guard belongs.

Nothing would seem to be more efficient than this as a cattle guard, and yet the road master states that in one case a certain man's cow had educated herself to such a point of excellence that she would deliberately and safely walk the champered stringers, placing right feet one side and left feet the other side of the rail. But this isolated instance of successful climbing cannot be considered due to any fault of the cattle guard.

Grade.—The steepest grade noted by the writer is 85 feet to the mile, though that is very likely exceeded in the State. Very little attention appears to have been given to controlling grade; or least possible maximum grade per division, or other portion of road. Neither to the matter of grade compensation for curvature. These questions appear to rise to great importance only on long stretches of road through uninhabited country like our western wastes, where it is not convenient to locate "helper engines" for an occasional excessive grade.

But in Ohio, a road master will reply, stating the steepest grade, and give its location; and also that it is perhaps ten feet or fifteen feet steeper than any other. He may say, also, that in each case the grade was made as small as possible, regardless of reduction of cost of road by allowing the grade to go up to the controlling maximum at any point on a portion to which this controlling maximum belongs.

Recently a number of the directors and officials of the Highland Railway Co. witnessed a series of experiments with the Westinghouse brake, over the Waverley route, for the purpose of satisfying themselves as to its efficiency, with a view to its adoption on the Highland lines. The train was composed of an engine, with 6 carriages and a guard's van; and the experiments consisted chiefly in pulling up while running at high rates of speed. The stoppage was repeatedly accomplished in distances of from 300 to 400 yards; on one occasion, in descending a gradient of 1 in 70, at the rate of 60 miles an hour, the train was brought to a stop within a distance of from 500 to 600 yards. Another test was the uncoupling of a part of the train while going at full speed, and the application of the brake. The result was that the latter portion was brought to a standstill almost immediately, while the front part was pulled up within less than 300 yards, notwithstanding that the steam was kept full on.

ON THE PROPER DIAMETER OF ELECTRIC CONDUCTORS.

By FREDERICK E. UPTON, U.S.N.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

It is proposed in the following paper to determine theoretically the proper diameter of electric conductors, regard being had (1) to their economy, and (2) to their adaptability to convey and distribute with uniformity electric energy to the various units of a system in which that energy is to be developed.

NOTATION.

Following is the notation which will be employed, certain values being assigned to some of the arbitrary constants for purpose of illustration:

a—A constant depending upon the material of the conductor (for copper about .000015.)

b—Price of material of conductor in cents per pound (for copper wire 35.)

C—Strength of current.

d—Diameter of conductor in inches.

h—Hours per day work is being performed (9.)

I—Interest on cost of conductor in cents per annum.

i—Yearly rate of interest in hundredths, (.10).

K—Cost of useless work developed in conductor in cents per annum.

k—In electric lighting, the estimated average proportion of lamps, in actual use during the time h, to the whole number of lamps in a system.

L—Length of conductor in feet.

l—Price of coal in cents per pound (.2).

M—$\dfrac{.0011735anhl}{sbi}$, (.000 000 09865).

N—Whole number of lamps or other units in a system.

n—Number of pounds of coal consumed in boiler per hour, for each horse-power of electrical energy developed in circuit (3.5).

P, p—Work in foot pounds per minute.

R, r—Resistance in ohms.

s—Weight of the material of conductor, in pounds to the cubic inch, (for copper wire .3212.)

DERIVATION OF THE FORMULA.

In any conductor

$$r=\frac{a\mathrm{L}}{d^2} \quad . \quad . \quad . \quad . \quad (1).$$

In a simple circuit the work developed in any part of it, during a given time, is proportional to the resistance of that part, whence

$$p=\mathrm{P}\frac{r}{\mathrm{R}}=\frac{a\mathrm{LP}}{\mathrm{R}d^2} \quad . \quad . \quad . \quad . \quad (2).$$

The capital letters refer to any object in the circuit in which useful work is to be developed, the small letters to the conductor.

$$\mathrm{K}=\frac{365pnhl}{33000}=\frac{.01106anhl\mathrm{PL}}{\mathrm{R}d^2} \quad . \quad . \quad . \quad (3).$$

$$\mathrm{I}=3\pi\mathrm{L}d^2sbi \quad . \quad . \quad . \quad (4).$$

Now if any infinitesimal increment, dd, positive or negative, be added to d, the resulting increments of K and I will be

$$d\mathrm{K}=-\frac{.0221anhl\mathrm{PL}}{\mathrm{R}d^3}\times dd \quad . \quad . \quad (5).$$

$$d\mathrm{I}=6\pi\mathrm{L}sbid\times dd \quad . \quad . \quad . \quad (6).$$

These expressions show what would be the increase or diminution of the cost of heating the conductor, and of the interest on the cost of the material of the conductor, resulting from an infinitesimal change in its diameter.

The negative sign of $d\mathrm{K}$ indicates that it progresses in a direction opposite to dd.

It is evident from inspection of (5) and (6) that a value may be assigned to d so large that the sign of $d\mathrm{K}+d\mathrm{I}$ will be the same as that of $d\mathrm{I}$; also one so small that the sign of $d\mathrm{K}+d\mathrm{I}$ will be the same as that of $d\mathrm{K}$; and, since $d\mathrm{K}$ and $d\mathrm{I}$ have contrary signs, there must be some value of d which will render

$$d\mathrm{K}+d\mathrm{I}=0 \quad . \quad . \quad . \quad (7).$$

Let that value be d'; if a positive increment is now applied to d', (7) will have the sign of $d\mathrm{I}$ which is the same as that

of dd', that is, increasing or +; or if a negative increment be applied to d', (7) will have the sign of $d\mathrm{K}$, that is, contrary to dd' or still +. Hence when $d\mathrm{K}+d'\mathrm{I}=0$, any increase or diminution of d' will result always in an increase of $d\mathrm{K}+d\mathrm{I}$, and the most economical diameter is thus determined.

Integrating (7)

$$\mathrm{K}=\mathrm{I} \quad . \quad . \quad . \quad . \quad . \quad . \quad (8).$$

numerically. Whence

$$d'^{2}=\sqrt{\frac{\mathrm{MP}}{\mathrm{R}}}=\sqrt{44.236\mathrm{M}}\,\mathrm{C} \quad . \quad . \quad . \quad (9).$$

L has disappeared, which shows that the most economical size of conductor is independent of its length.

Formula (9) gives correct results for insulated wire, if b is made to equal the price of the material of the conductor per pound, plus the price of the insulation covering a pound, when that is constant for the different sizes. It also may be readily adapted to any other source of energy than coal.

APPLICATION OF THE FORMULA TO ELECTRIC LIGHTING.

Let p_1 be the foot pounds of work per minute required for one light, at a standard brilliancy, r_1, the resistance of one light.

I. In a *simple* circuit, where the lights are connected in series, $\mathrm{R}=k\mathrm{N}r_1$, $\mathrm{P}=k\mathrm{N}p_1$. Hence

$$d_s'^{2}=\sqrt{\frac{\mathrm{M}p_1}{r_1}} \quad . \quad . \quad . \quad . \quad . \quad (\mathrm{A}).$$

Or, in a simple circuit, d'_s is independent of the number of lamps, and depends solely upon the elements of a single lamp, as might have been inferred from the disappearance of L referred to above.

II. In a *multiple* circuit, neglecting the conductors, $\mathrm{R}=\frac{r_1}{k\mathrm{N}}$, $\mathrm{P}=k\mathrm{N}p_1$; let the unknown resistance of the conductors be the q part of $\frac{r_1}{k\mathrm{N}}$; then $\mathrm{R}=\frac{r_1}{k\mathrm{N}}(q+1)$. As the work developed in a circuit, increases in the same proportion as the resistance (C being constant), $\mathrm{P}=k\mathrm{N}p_1(q+1)$, and (9) becomes

$$d'^{2}_m=k\,\mathrm{N}\sqrt{\frac{\mathrm{M}p_1}{r_1}} \quad . \quad . \quad . \quad (\mathrm{B}).$$

Or, in a multiple circuit, d'_m is independent of the lengths of the conductors or any of them, and depends on the elements of a single lamp and the number of lamps.

For any description of lamp, $d'_m{}^2$ and the gauge number may be tabulated for $k\mathrm{N}$.

III. If, however, in a multiple circuit, the sizes of conductors are calculated by (B), the different lights of a system will not be of uniform brilliancy, unless they are all at the same distance from the generator following the route of the current. Otherwise, those nearest the generator will be the brightest.

Consider a circuit divided into two circuits, numbered 1 and 2, and containig m and n lamps respectively; the conductors to which these lamps are attached will be called the connecting wires, and the lamps are supposed to be attached to them in multiple circuit without any other resistance than that of the lamps themselves, that is, $\frac{r_1}{m}, \frac{r_1}{n}$. Then by (B), $d_1'^{2} : d_2'^{2} :: m : n$, or the current and work will divide correctly if the resistance of the connecting wires be neglected, and enter each circuit according to the number of lights to be supplied. But the connecting wires have resistances, which should manifestly be in the same ratio as that of the lamps in circuits 1 and 2, in order for the work still to be distributed correctly; that is, we must have

$$r_1 : r_2 :: \frac{1}{m} : \frac{1}{n} :: \frac{1}{d_1'^{2}} : \frac{1}{d_2'^{2}}$$

But from (1)

$$r_1 : r_2 :: \frac{\mathrm{L}_1}{d_1'^{2}} : \frac{\mathrm{L}_2}{d_2'^{2}}$$

In order for the first proportion to obtain, L_1 must equal L_2, which is the condition of uniform brilliancy. The same is true of any number of parallel circuits; the connecting wires must be of such length as to bring all the lamps to the same distance from the generator.

In practice the lengths of the connecting wires are determined by local circumstances, and, therefore, they will not generally have the proper resistance for uniform distribution of work. It will, hence, be necessary to modify their computed diameters.

Let some constant distance, L′, be assumed, to which the distances of all the lamps from the generator must be made equivalent as regards resistance. Designate the actual length of the connecting wire by L, and the length it should have to bring the lamp to the distance L′ from the generator byD. Then there will result for *connecting wires* only

$$d'^{2}_{cm} = kN\sqrt{\frac{Mp_1}{r_1}}\,\frac{L}{D} = d'^{2}_{m}\,\frac{L}{D} \quad . \quad . \quad . \quad (C).$$

L′ must be at least nearly equal to the distance of the farthest lamp from the generator, always following the route of the current.

All the conductors, except the connecting wires, are given by (B). The turning on or off of any number of lamps will not affect the uniformity of the brightness of the rest.

The system as thus arranged may be replaced, for most purposes of computation, by an equivalent system, consisting of *k*N lamps arranged like a chandelier, connected with the generator by a conductor whose length is L′ and whose diameter is given by (B).

Applying the formula (B) to find the size of the main conductor, leading from the generator to the first derivation, to supply 1200 lamps of Edison's pattern, where $p_1 = 3000$, $r_1 = 130$, assigning to M the value previously given under the head of Notation and to k .5, then there results, $d'_m = .95$ inches. This is also the diameter of the conductor of the theoretical system just referred to.

GENERAL APPLICATION.

Formulæ (B) and (C) may be used to determine the proper size of conductors in all cases where economy would be a matter of importance, such as the storage of electricity at a distance, or the transmission of power to any number of secondary electric machines. The formulæ will then take the general form:

$$d'^{2} = \frac{N}{Q}\sqrt{\frac{Mp_1}{r_1}} \quad . \quad . \quad . \quad . \quad (D).$$

Where Q is the number of cells, machines, &c., connected end on in each series, and $\frac{N}{Q}$ is the number of of series. The arrangement in any particular case depends on the ratio of the elements of the generator to those of a single unit of the receiving system.

ON THE STRENGTH OF WROUGHT-IRON BRIDGE MEMBERS; INCLUDING STRUTS, COLUMNS, SEMI-COLUMNS, BEAMS, &c.

By S. W. ROBINSON, C. E., Prof. Mech. Eng. in the Ohio State University, Columbus, Ohio; Member of the Ohio State Board for Inspection of Railroads and Bridges.

Written to accompany Report to the Hon. H. SABINE, Commissioner of Railroads and Telegraphs.

I.

THE examination of bridges for strength and trustworthiness has occasioned the use of formulas not accessible to the writer in published form. In procuring the formulas by direct solution, the amount of labor entailed has been great. The avoidance of a repetition of this labor on the part of others who may require these formulas, is believed to be sufficient reason for now publishing the results obtained.

To make clear the nature of the formulas required, the conditions to which certain bridge members are subject may be referred to. Thus, in some instances, the chords of truss bridges are required to carry the floor beams, one, two or more of them, to each panel. Now, when a train of cars comes upon a bridge, the floor-beam loads rest down upon the chord members and deflect them into downward bowing curves, causing "transverse strains," or "bending moments." Simultaneously, the load upon the bridge causes endlong strains in the same chord members; tension for the lower, and compression for the upper chord. Thus, an individual member of the chord of the bridge, such as an "eye bar," is to be treated as a beam subjected

to a combined bending and stretch, or bending and compression, as the case may be.

The usual way of calculating the resulting maximum strain in the piece considered, is to compute as though the beam had only the "cross strain," and then compute separately for the endlong strain, and add the results. It is evident, however, from a casual consideration that as the bending load would separately give a certain curve to the beam, the tension would partially straighten that curve and diminish the bending moment. Again, in a compressive endlong strain, the curvature of the beam would be increased and the bending moment increased. Hence, the usual calculation would give too large a value to the maximum strain per square inch in one case, and too small in the other. The formulas given in this article correct these anomalies.

The conditions of the piece just referred to as regards loading and supports are stated in general terms, but it is evident that they include all such special conditions as concentrated loads; distributed loads; one end fixed and the other free; one end fixed and the other supported; both ends supported; both ends fixed, &c.

TRUE FLEXURAL MOMENT AND ITS RESISTANCE IN MIXED STRAINS.

Before proceeding to special cases, it is necessary to consider the pseudo-philosophy of eccentric neutral axis in beams subject to both endlong and cross forces.

For the sake of fixing the ideas, let Fig. 1 represent a beam fixed at the end, B, and free at the end, A. Let the cross force, P, act at right angles to the beam, and the endlong force, T, in the direction of the length, both being applied at the free end of the beam. The bending will be as shown, the fibers on the upper side of the beam being stretched, and those on the lower side being compressed, if T is not too great.

Now, undoubtedly one effect of T is to elongate the whole beam and every part of it, throwing the neutral axis for all the stresses, downward from the line ACB to some line C′B′, or C″B″ This displacement is proportional to $\frac{T}{Px}$ for the section at the distance x, from the free end of the beam. If $T=o$, the displacement $=o$, anywhere. If $P=o$, the displacement is ∞, anywhere. If $x=o$, the displacement $=\infty$. If $x=l$, and P very small, the displacement is very great. But for T and P moderate, the displacement is moderate. For T and P constant and x variable, the departure of the line of the neutral axis, C′B′ from CB, increases as x decreases, and, geometrically speaking, it is asymptotic to the horizontal through B, and to the vertical, through A. Though this line is a real *neutral* axis, as regards stress, it can easily be shown that it is not the most convenient line in which to place the origin of moments, for the well known differential equation of the elastic curve, viz.:

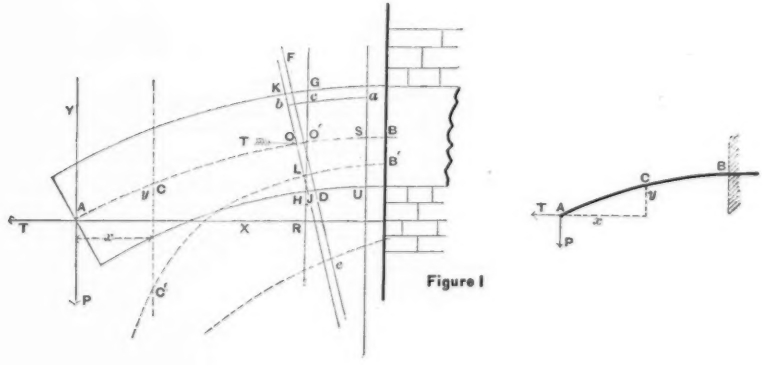


Figure 1

$$\varepsilon I\frac{d^2y}{dx^2}=\Sigma Px=\Sigma(\text{applied moments}),$$

$$=M \quad . \quad . \quad (1)$$

This equation, as it stands, is an equation of moments of forces, the second member being the sum of the moments of the forces acting on the beam, while the 1st member is the sum of the moments of the internal forces of the beam resisting bending, or, more briefly, the "moment of resistance" of the beam. The origin of moments, or moment axis for this equation, is taken on some certain cross section of the beam, as, for instance, DF, and then the moments of the forces are to be expressed for that particular origin of moments. The equation is then integrated, resulting in the equation of the elastic curve. The effect of the integration is to move the plane, D F, from end to end of beam, thus summing the bending effects due to each element of length of beam.

That the origin of moments for the above equation of moments should be taken on the sectional plane, DF considered, no one doubts; but *where* it should be taken is seriously questioned. Some writers definitely locate it, by saying that the moment of inertia, I, is here variable, the neutral axis not being parallel to the beam. According to this, if C′B′ be the neutral axis, as above described, the origin of moments must be taken at L, in applying the above general equation (1) to Fig. 1. The moment of inertia, I, of the section, DF, is then to be expressed for the moment of inertia axis at L, coinciding with the origin of moments. Now, to discuss this conclusion, draw G H, DF, and JK, as shown. Let the portion, SO, of the beam be supposed to stretch, displacing DF to JK, this stretch being due to T. Again, let the bending moments displace GH, through an angle to FD, causing a stretch in the upper fibers and a compression in the lower fibers of the beam, the triangles, O′FG and O′HD, representing the two actions respectively. Respecting a fiber, *ab*, the stretch from the line, G, to F is due to cross strain, and from F to K, to endlong strain.

Now, for the sake of an argument, let it be granted that the origin of moments for equation (1) be taken on the real neutral axis, C′B′, at L. This point is where the cross section, JK considered, intersects the real neutral axis. That is, L is the point in the section, J K, where there is actually no longitudinal stress. The figure indicates this, since at the top of the beam, GF stands for stretch due to cross strain; FK, the stretch for endlong strain, their sum, GK, being the total stretch or stress. This stress is less and less in going down from the top, until it vanishes at L, where the limiting lines, GL and KL, for the stress named, intersect on the neutral axis, C′B′.

Now, in applying equation (1) to the beam, Fig. 1, with the understanding that the *origin of moments be taken at* L, we have

$$\frac{\varepsilon I}{\rho}=\varepsilon I\frac{d^2y}{dx^2}=P.AR-T.RL \quad . \quad . \quad (2).$$

where the moment of inertia, I, of the first member, is to be so expressed that its axis coincides in position with the origin of moments, L. Let the beam be regarded as uniform in cross section from end to end, with the line, ACOB traversing the center of gravity of any cross section. Let I_1 represent the moment of inertia of the cross section considered, for an axis located at the center of gravity of that section. For KJ this axis is at O, the point *o* being the "principal axis" or "center of inertia." Now, a well-known principle in mechanics, by which I may be obtained from I_1, gives

$$I=I_1+\text{section JK}.\overline{LO}^2 \quad . \quad (3).$$

Hence the first member of equation (2) is

$$\frac{\varepsilon I}{\rho}=\frac{\varepsilon I_1}{\rho}+\frac{\varepsilon}{\rho}\text{ section JK}.\overline{LO}^2$$

$$=\frac{\varepsilon I_1}{\rho}+\frac{\varepsilon}{\rho}K.\overline{LO}^2 \quad . \quad . \quad (4).$$

where K is here taken for the cross section JK.

The denominator ρ is the radius of curvature of the curve of the neutral axis as shown in Fig. 1.

If S U and G H be taken parallel before flexure and fixed to the beam, SO being regarded as an element of length, *dx*, of the beam, then during flexure S U and G H intersect at the center of curvature of the elastic curve, thus determ-

ining ρ. Then, relative to the fiber S O′ O, Fig. 1, we will have the stretch of the fiber = O′ O; and from the similarity of triangles we may write

$$OL : \rho :: O'O : SO.$$

$$\therefore \quad \frac{LO}{\rho} = \frac{O'O}{SO}$$

A well-known fundamental formula in the theory of the elastic resistance of beams is

$$T\,l = \varepsilon\,K\,d\,l \quad . \quad . \quad . \quad (4\tfrac{1}{2}).$$

where T is a force applied to a bar of length, l, of section K, and co-efficient of elasticity, ε; for which the stretch is $d\,l$. This formula may be applied to the part S O′ of the beam Fig. 1 by making l = S O′ and $d\,l$ = O′ O, the section, K, being the same whole section, J C. In this, the dl is = O′ O = F K = D J.

Hence

$$T.SO' = \varepsilon K.O'O = \varepsilon K.\frac{LO}{\rho}.SO$$

or

$$T = \varepsilon K\frac{LO}{\rho}$$

combining this with (4), we get

$$\frac{\varepsilon I}{\rho} = \frac{\varepsilon I_1}{\rho} + T.LO$$

Comparing with equation (2) we have

$$\frac{\varepsilon I}{\rho} = \frac{\varepsilon I_1}{\rho} + T.LO = P.AR - T.RL$$

or

$$\frac{\varepsilon I_1}{\rho} = P.AR - T.RL - T.LO$$

$$= P.AR - T\,(RL + LO)$$

or

$$\frac{\varepsilon I_1}{\rho} = \varepsilon I_1 \frac{d^2y}{dx^2} = P.AR - T.RO. = M$$

$$= \Sigma Px - \Sigma Ty \quad . \quad . \quad (5).$$

This equation has for its first member the ordinary expression for the moment of elastic resistance of beams, subject simply to bending forces applied only at right angles to the beam; that is to say, the expression in which the origin of moments for the resisting forces is at the center of gravity of the cross section of beam considered, or at O, Fig. 1. The second member expresses simply the moments of the applied forces for the same origin of moments, viz.: the point O.*

Hence it follows that in cases of flexure of beams, where part of the forces are applied in an endlong or longitudinal direction, the moments may unhesitatingly be expressed with reference to an origin of moments located at the center of gravity of the cross section considered. Equation (5) makes this evident, not only for the moment of resistance but for the entire number of the applied forces. Indeed, a little consideration of M, in equation (5), shows that the above statement respecting the moment of the applied forces is true in general; that is to say, it is true for any number of forces, having any conceivable points of application, and having any conceivable lines of direction. For each force may be resolved into two components, one longitudual and the other transverse; T.RO being the algebraic sum of the moments of all the former and P.AR of the latter. It is to be understood that in the integrations, proper limits are to be chosen, so that no point of concentration of applied force be overstepped in this, any more than in ordinary problems.

These facts place all problems in the resistance of beams on the same basis, that is to say, equation (5) applies with equal truth and exactness for a beam subject to the action of any system of forces, however complex, as for the simple case of a single transverse force; I_1 being always regarded as the principal moment of inertia and constant for a beam of uniform cross section.

This complete generalization of equations (1) and (5) for a constant value of I is important, since the integrations are not only facilitated, but we are enabled to apply the resulting formulas for a beam under any system of forces, with the same degree of confidence as for the most simple case.

To confirm the facts above stated by discussion, let us refer to Fig. 1. First,

* In the above transformation the radius of curvature ρ has been all the time regarded as of the same value. Fig. 1 shows that this is correct. For in $\frac{\varepsilon I}{\rho}$ it extends from L to the center of curvature, or to where L J produced meets SU produced. In $\frac{\varepsilon I_1}{\rho}$ it extends from O′ to where O′D intersects SU produced. But as LJ and O′D are parallel to each other the radii of curvature have the same value.

suppose P applied, bending the beam downward as shown. Then apply T as shown. This latter will evidently partially straighten the curvature, and raise the end of the beam. But it will finally come to rest under some degree of curvature, P and T both acting. The portion S O′ of the beam will stretch, D F moving to J K. Next apply an equal and opposite endlong force—T, at the center of gravity O, of the cross-section J K. This latter will have no tendency whatever to bend the portion S O, but it will exactly return J K to D F. In this the end of the beam will not be raised or lowered, the deflection being entirely due to the two forces acting at the end of the beam. The stress in the beam is now simply that represented by the triangles O′ G F and O′ D H. The moment of resistance is $\frac{\varepsilon I_1}{\rho}$ axis for I_1 being at O′, and the moment of P will be P.AR. But as to T we have a *couple* between T at the line AR and—T at O′ the arm of the couple being RO. Hence the moment of this couple is T.RO′. All these moments are seen to have the origin of moments at the point O, or O′ both being practically the same point. This re establishes equation (5).

So far, the endlong force, when spoken of in connection with Fig. 1, has been treated as producing tension. But it is easily seen that similar reasoning follows for T, so taken as to compress the beam. Indeed, the algebraic sum, T.OR, mentioned above, contemplated positive as well as negative forces.

Equation (5) enables us to find the equation of the elastic curve of the bent beam. Having the equation of the curve, we can readily find the deflection at any point. Also the moment of strain M, may be found as soon as the unknown constants of integration are determined.

TRUE MAXIMUM STRAIN IN ANY CROSS SECTION.

By aid of the moment M and the endlong force T, we may find the maximum strain produced in any cross section of the beam, as for instance in the section at O, Fig. 1. At the top of the beam, the strain is GK, and at the bottom it is JH; GK being the greater, it is the one sought.

The strain GK is the sum of two parts, GF and FK, the former being due to the moment M of bending, and the latter to the direct tension T. To find the total amount of this strain per square inch, we may apply the well known formula for the strength of beams for finding the part GF thus

$$\frac{t_1 I_1}{d_1} = M, \quad . \quad . \quad . \quad . \quad (6).$$

where M is given by equation (5), as the algebraic sum of the moments of all the applied forces, the center of gravity of the section considered being the origin of moments, I_1 the *principal* moment of inertia for the same section, as previously stated, d_1 the distance from the center of gravity of the section to that point where the strain is greatest, and t_1 is the strain due to the moment M. In Fig. 1 O′ is the center of gravity of the section DF considered, I_1 is the moment of inertia of that section for O′ the axis, and d_1 is O′F. As a formula for determining the moment of ultimate resistance of beams, t_1 is to be assumed equal the ultimate resistance or modulus of resistance to rupture. Equation (6) is the converse of this, where M is predetermined and t_1 found as a stress considerably below the ultimate value. In calculating the ultimate strength of beams, formula (6) is known to give values wide of the truth. This is due to the fact that the law of resistance in the neighborhood of rupture deviates greatly from the law of perfect elasticity. But within the elastic limits, as will usually be the case with (6), the formula, as is well known, will be truthful. The strain FK Fig. 1, as above explained is due to T, and if the intensity be represented by t_2 and the sectional area DF by K, we will evidently have

$$t_2 K = T \quad . \quad . \quad . \quad . \quad (7)$$

Let t, = GK, Fig. 1, stand for the whole maximum strain per square inch in the section considered.

Then

$$t = t_1 + t_2 = \frac{M d_1}{I_1} + \frac{T}{K} \quad . \quad . \quad . \quad (8).$$

a perfectly general formula, free from all assumed approximations except in the instance where ρ is placed equal the

second differential co-efficient. This, however, is done by all writers on beams. But it is known that the error in this assumption is of no practical import whatever in beams as ordinarily used. It is zero where the bent beam is not inclined to the axis x, and for an inclina- of 10° it is less than 5 per cent.

It is to be observed that for rupturing strains d_1 is to be taken as the distance from the center of gravity of the section to the point where the rupture takes place, whether it be by tension or compression.

When the beam is rectangular in cross section with a breadth b and depth d, we have

$$d_1=\frac{d}{2},\ I_1=\frac{bd^3}{12},\text{ and } K=bd,$$

and also equation (8) agree in making $t_1=0$ and hence, for minimum strains,

$$M=o,\text{ and } t_1=o.$$

To illustrate further, take an "eye bar" of a lower chord of any bridge. Let ABCD represent the loads due to floor beams. The section at the middle of the length will receive the greatest moment of strain due to ABC, &c., while the tension T is uniform throughout. Now, that $t_1=o$, the centers of the eyes must be raised a distance ab, shown at the middle section, so that for the maximum bridge load,

$$T.ab=\left\{\begin{array}{l}\text{sum of the moments of AB and}\\ \text{P, with respect to } a\end{array}\right. \quad . . (10).$$

When this condition is exactly satisfied, the middle part of the beam near

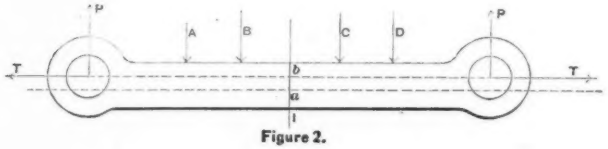


Figure 2.

and hence (8) becomes,

$$t=\frac{6M}{bd^2}+\frac{T}{bd} \quad . . . \quad (9).$$

Here d_1 disappears, as indeed it will in all cases where the cross section of the beam is symmetrical with respect to an axis to that section taken horizontal through O′ Fig. 1.

NEUTRALIZING OF MOMENTS DUE TO CROSS STRAINS.

It is often desirable to so assume the point of application of T, as to place the beam under the least possible maximum stress when the structure containing the the beam receives its maximum load. For instance, suppose the lower chord of a bridge carries the floor beams, several to each panel. Then it is evident that T may be applied at such point as to make its moment, with respect to the section of beam in question, equal and opposite to the moment of P. This makes M = 0, and consequently $t_1=0$. This is evidently the best condition, since t_2 and T are sole and mutual dependencies, and, at best, the minimum strain can never fall below t_2. This, JK will be simply stretched and not sprung into curvature. But if the body of the bar be straight when free from strain, it will, when under the condition, (10) be sprung at points near the eyes. The problem then becomes complex because ab varies with the spring, and would require to be determined with due regard to the amount of flexure, as subsequently done in this article.

But it is possible to so curve the bar in the manufacture, that any part of it will be simply stretched when bearing its maximum load. To indicate a few of the simpler forms, suppose only a single floor beam at the middle of the bar at K. Then the center line of the bar should be a straight line from a, Fig. 2, each way, to the centers of the eyes, the distance ab being formed by (10). If there were two floor beams on the link, say A and D only, then the link should be straight between A and D, and also between these points and the centers of the eyes, the lines from point to point being constantly at mid-depth of the body of the bar. If the floor beams were so numerous as to be treated as constituting a uniformly distributed load, the curve of

the center line of the body of the link would be a parabola running from center to center of eyes, with vertex at a, and with the principal axis vertical. Equation (10) would still determine ab, the 2d member being regarded as the sum of the movements of all forces except T. For this case the equation would take the form,

$$T.ab = P\frac{l}{2} - \frac{wl^2}{8} \text{ for the middle point,}$$

and (11).

$$Ty = Px - \frac{wx^2}{2} \text{ for any point,}$$

the origin of co-ordinates being at the middle of one eye, with l the length of the bar, and w the loading per unit length.

In cases where the cross section of the beam is non-symmetrical, as often the case in upper chords of bridges, the center of gravity of that section is to be found and then ab laid off, downward in the upper chord and upward in the lower chord.

When chord members are very long, the moment due to their own weight should be found and ab determined by (11).

GENERAL INTEGRALS FOR SOLVING CASES OF MIXED STRAINS.

In the designing of new structures the precautions pointed out above relative to maximum stresses in mixed strains may be provided for in the simplest way, viz: by computing separately and adding, though this may not always be preferable. When this approximate method is not desirable, and in cases where existing structures are to be examined, it may become necessary to make a careful determination of the moment M. To meet this requirement the various cases following have been worked out.

Before taking up the special cases an examination of the expressions for the moments of applied forces, shows that the integrations all come under two general forms, and it will be seen to be decidedly preferable to perform the two integrations once for all than to integrate for each special case.

The first general form is

$$\frac{d^2y}{dx^2} = Ay + Bx + Dx^2 + F \quad . \quad (12).$$

Differentiate twice, and

$$\frac{d^4y}{dx^4} = A\frac{d^2y}{dx^2} + 2D.$$

Now put

$$\frac{d^2y}{dx^2} = n,$$

and differentiate twice,

$$\frac{d^4y}{dx^4} = \frac{d^2n}{dx^2} = A\frac{d^2y}{dx^2} + 2D$$

or

$$\frac{d^2n}{dx^2} = An + 2D$$

multiply through by dn, and integrate, and we get

$$\frac{dn^2}{dx^2} = An^2 + 4Dn + C$$

or

$$dx = \frac{dn}{\sqrt{A}\sqrt{n^2 + \frac{4Dn}{A} + \frac{C}{A}}}$$

whence, by integration

$$x = \frac{1}{\sqrt{A}} \text{hyp. } \log \frac{\frac{2D}{A} + n + \sqrt{n^2 + \frac{4Dn}{A} + \frac{C}{A}}}{C_1}$$

Passing to exponentials and transposing in part,

$$C_1 e^{x\sqrt{A}} - \frac{2D}{A} - n = \sqrt{n^2 + \frac{4Dn}{A} + \frac{C}{A}}$$

By squaring both members and canceling

$$C_1^2 e^{2x\sqrt{A}} - \frac{4D}{A} C_1 - e^{x\sqrt{A}} - 2C_1 n e^{x\sqrt{A}} + \frac{4D^2}{A^2} = \frac{C}{A}$$

solving for n we obtain

$$\left.\begin{aligned} n = \frac{C_1}{2} e^{x\sqrt{A}} - \frac{C}{2C_1 A} e^{-x\sqrt{A}} \\ - \frac{2D}{A} + \frac{2D^2}{C_1 A^2} e^{-x\sqrt{A}} \\ = \frac{d^2y}{dx^2} = Ay + Bx + Dx^2 + F \end{aligned}\right\} (13)$$

The second general form is

$$\frac{d^2y}{dx^2} = -Ay - Bx - Dx^2 - F \quad . \quad (14).$$

Differentiate twice and

$$\frac{d^4y}{dx^4}=-A\frac{d^2y}{dx^2}-2D$$

Put

$$\frac{d^2y}{dx^2}=+n$$

and differentiate twice

$$\frac{d^4y}{dx^4}=\frac{d^2n}{dx^2}=-A\frac{d^2y}{dx^2}-2D$$

or

$$\frac{d^2n}{dx^2}=-An-2D$$

Multiply through by dn and integrate and

$$\frac{dn^2}{dx^2}=-An^2-4Dn+C'$$

or

$$dx=\frac{dn}{\sqrt{C'-4Dn-An^2}}$$

But

$$\int\frac{dz}{\sqrt{a\pm bz-cz^2}}=\frac{1}{\sqrt{c}}\sin^{-1}\frac{2cz\mp b}{\sqrt{4ac+b^2}}$$

where $a=C'$, $b=4D$, $c=A$, $z=n$.

Hence

$$x=\frac{1}{\sqrt{A}}\sin^{-1}\frac{2An+4D}{\sqrt{4AC'+16D^2}}-C_1'$$

or

$$\sin(x\sqrt{A}+C_1')=\frac{An+2D}{\sqrt{AC'+4D^2}}$$

Solving for n, we obtain

$$\left.\begin{aligned}n&=\frac{\sqrt{AC'+4D^2}}{A}\sin(x\sqrt{A}+C_1')\\-\frac{2D}{A}&=\frac{d^2y}{dx^2}=-Ay-Bx-Dx^2-F\end{aligned}\right\}(15).$$

In the application of (13) and (15) to the following cases, it is only necessary to cut out any redundant term, and determine the constants of integration.

SOME OF THE PRINCIPAL CASES UNDER MIXED STRAINS.

I. *For the first case let the beam be fixed at one end, free at the other, and having a load P and pull T applied at the free end.* Fig. 1 or 1a represents it. The first question arising is whether to apply (13) or (15). An inquiry will reveal the fact that the sign of Ty determines which. The calculus demands that the ordinate and second differential coefficient have contrary signs when the curve is concave toward the axis of x. Hence in Fig. 1 they are contrary. Taking T positive when it is directed toward the beam, and negative when from it, we

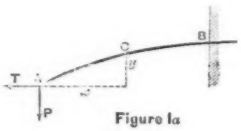


Figure 1a

will have, for T pointing outward as in Fig 1 or 1a.

$$-\varepsilon I_1\frac{d^2y}{dx^2}=Px-Ty=M$$

T being negative makes the sign of $\frac{d^2y}{dx^2}$ and Ty alike.

For convenience let the subscript to I be dropped in the following equations, I being always regarded as the principal moment of inertia of the cross section of the beam. Then we have for the origin of moments at C, Fig. 1a, and of coordinates at A,

$$\varepsilon I\frac{d^2y}{dx^2}=Ty-Px=M \quad \ldots \quad (16).$$

To integrate this equation, we require (13) because the signs of Ty and Ay are alike, also of the second differential coefficients.

Comparing with (13)

$$A=\frac{T}{\varepsilon I} \quad B=-\frac{P}{\varepsilon I} \quad D=o \quad F=o$$

Hence

$$\frac{d^2y}{dx^2}=Ay+Bx=\frac{C_1}{2}e^{nx}-\frac{C}{2C_1A}e^{-nx}$$

where for convenience $n=\sqrt{A}=\sqrt{\frac{T}{\varepsilon I}}$

n here differing from the n used in the integrations for (13) and (15). This equation is given in *Strength of Materials*, by De Volson Wood, p. 300, 2d ed.

Let the length of the beam be l, and the distance of the point of application of T below the center of gravity of the end of the beam be h. Then if $x=o$ $y=h$, and

$$Ah=\frac{C_1}{2}-\frac{C}{2C_1A}$$

$$\therefore$$

$$\frac{C}{2C_1A}=\frac{C_1}{2}-Ah$$

and

$$Ay+Bx=\frac{C_1}{2}\left(e^{nx}-e^{-nx}\right)+Ahe^{-nx}$$

$$A\frac{dy}{dx}+B=\frac{C_1}{2}\left(e^{nx}+e^{-nx}\right)-Ahne^{-nx}$$

But

$$\frac{dy}{dx}=o \text{ for } x=l \text{ and}$$

$$B=\frac{C_1}{2}n\left(e^{nl}+e^{-nl}\right)-Ahne^{-nl}$$

The value of C_1 from this, introduced above, gives

$$Ay+Bx=\frac{\frac{B}{n}+Ahe^{-nl}}{\underset{e}{nl}+\underset{e}{-nl}}\left(e^{nx}-e^{-nx}\right)+Ahe^{-nx}$$

Restoring the values of A and B, we get

$$Ty-Px=-\left(\frac{P}{n}-The^{-nl}\right)\frac{e^{nx}-e^{-nx}}{\underset{e}{nl}+\underset{e}{-nl}}+The^{-nx}$$

$$=M \quad . \quad . \quad . \quad . \quad . \quad (17).$$

This equation expresses the relation between x and y for the equation of the curve of the axis of the beam, that is to say, of the curve AOB, Fig. 1 or 1a. The maximum deflection of the beam is y_1-h for $x=l$.

Also (17) is so arranged as to give the moment of the applied forces for any point, the first member being the same as (16).

If $x=o$ $y=h$ as it should.

The maximum moment of strain for the whole beam is evidently at the fixed end where $x=l$ and $y=y_1$. Hence, by reduction,

$$Ty_1-Pl=-\frac{\frac{P}{n}\left(e^{nl}-e^{-nl}\right)-2Th}{\underset{e}{nl}+\underset{e}{-nl}}$$

$$=M_{max} \quad . \quad . \quad . \quad . \quad (18).$$

When $h=o$,

$$Ty_1-Pl=-\frac{P}{n}\left\{\frac{e^{nl}-e^{-nl}}{\underset{e}{nl}+\underset{e}{-nl}}\right\}=M_{max}. \quad (19).$$

with h restored and $P=o$

$$Ty_1=\frac{2Th}{\underset{e}{nl}+\underset{e}{-nl}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (20).$$

Evidently the resultant of T and P might be substituted, and be considered as a single force acting obliquely. Conversely any single force acting obliquely at the end of the beam could be resolved into components corresponding with T and P.

If we imagine this resultant acting at the end of h, its prolongation would intersect the beam when h is downward. This point of intersection would evidently be a point of contrary flexure at which the moment would be zero. The point could be found by placing the 2d member of (17) $= o$ and solving for x. This point would be a neutral point for an S shaped curve.

II. *Let the conditions be as in* I, *except change T to a push.*

This would seem to be met by changing the sign of T, but this makes all the expressions in case I imaginary. But it may be rationalized as done in Prof. Wood's *Strength of Materials*, p. 301, 2d ed. But if we change the sign of P instead of T, the relation of signs of T and P is right. In applying equation (19) with sign of P changed, we will obtain a negative result for y, while when P is positive y is positive. Hence the conditions for this supposition are as shown in Fig. 3, with no essential change. It is

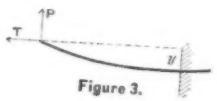


Figure 3.

simply case I turned over. The moment obtained from (19) is the same numerically for P + as for − which is evidently as it should be, while for T changed in sign it would be greater.

Hence, changing the sign of T, our equation of moments for this case becomes, as evident from Fig. 4, for the origin of moments at C and of co-ordinates at A.

$$\varepsilon I\frac{d^2y}{dx^2}=-Ty-Px=M \quad . \quad . \quad . \quad (21)$$

This may be integrated by aid of equation (15), as the signs are proper to it, where,

$$A=\frac{T}{\varepsilon I}=n^2 \quad B=\frac{P}{\varepsilon I} \quad D=o \quad F=o$$

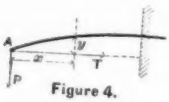


Figure 4.

Hence the integral is

$$-Ay-Bx=\sqrt{\frac{C}{A}}\sin(x\sqrt{A}+C_1)$$

$$=\sqrt{\frac{C}{A}}\sin\ (nx+C_1)$$

For $x=o$ let $y=h$ and

$$-Ah=\sqrt{\frac{C}{A}}\sin\ C_1$$

$$-Ay-Bx=-\frac{Ah}{\sin C_1}\sin(nx+C_1)$$

Differentiate and,

$$-A\frac{dy}{dx}-B=-\frac{Ahn}{\sin C_1}\cos(nx+C_1)$$

But

$$\frac{dy}{dx}=o \text{ for } x=l$$

$$\therefore \quad B=Ahn(\cos\ nl\ \cot C_1-\sin\ nl)$$

or

$$\text{Cot } C_1=\frac{B}{Ahn\cos nl}+\text{tang } nl$$

Hence

$$-Ay-Bx=-\frac{B}{n}\frac{\sin nx}{\cos\ nl}$$

$$-Ah\ (1+\text{tang } nx \text{ tang } nl)\cos nx$$

or, restoring the values of A, B and n, we get the general equation of the curve of the axis of the beam, also the moment at any point,

$$-Ty-Px=-\frac{P\sin nx}{n\cos nl}-$$

$$Th(1+\text{tang}nx\text{tang}nl)\cos nx=M \quad . \quad (22).$$

The maximum moment of flexure occurs where $x=l$ and $y=y_1$, which is

$$-Ty_1-Pl=-\frac{P}{n}\text{tang}nl-\frac{Th}{\cos nl}=$$

$$M_{\cdot\max} \quad . \quad . \quad (23).$$

when $h=o$

$$-Ty_1-Pl=-\frac{P}{n}\text{tang}nl=M_{\cdot\max} \quad . \quad (24).$$

When h is restored, and $P=o$

$$-Ty_1=-\frac{Th}{\cos nl}=M \quad . \quad . \quad (25).$$

III. *Let the beam be conditioned as represented in Fig. 5, viz.: fixed at one end, free at the other, with a load* P *and a pull* T *at the free end, and a uniform load over its length.*

Let w = distributed load per unit length of beam.

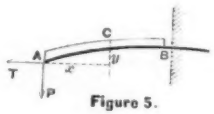


Figure 5.

Then the equation of moments will be

$$\varepsilon I\frac{d^2y}{dx^2}=Ty-Px-\frac{wx^2}{2} \quad . \quad . \quad . \quad (26).$$

Hence

$$+Ay+Bx+Dx^2=\frac{C_1}{2}e^{nx}-$$

$$\frac{Ce^{-nx}}{2C_1n^2}-\frac{2D}{n^3}+\frac{2D^2}{C_1n^4}e^{-nx}$$

where

$$A=\frac{T}{\varepsilon I}=n^2 \quad B=-\frac{P}{\varepsilon I} \quad D=-\frac{w}{2\varepsilon I}$$

To determine the constants of integration make x and y zero for the point A. This gives

$$\frac{C}{2C_1n^2}=\frac{C_1}{2}-\frac{2D}{n2}+\frac{2D^2}{C_1n^4}$$

Introducing this, differentiating, and making $\frac{dy}{dx}=o$ for $x=l$ we get

$$\frac{C_1}{2}=\frac{B+2Dl+\frac{2D}{n}e^{-nl}}{\left(e^{nl}+e^{-nl}\right)n}$$

which introduced, gives us the following general equation of moments, and of the curve of the axis of the beam T, P and w being restored.

$$Ty - Px - \frac{wx^2}{2} = -$$

$$\frac{P + wl + \frac{w}{n}e^{-nl}}{n}\left(\frac{e^{nx} - e^{-nx}}{e^{nl} + e^{-nl}}\right) + \frac{w}{n^2}\left(1 - e^{-nx}\right) \quad . \quad . \quad . \quad . \quad (27).$$

In this equation the sign of P may be + or −; that is, P may act down or up. Under certain circumstances the beam will be S shaped, with a point of contra flexure, or of zero moment.

To ascertain this point place the second member $= o$ and solve for x.

The maximum moment is evidently obtained by making $x = l$. The equation then will reduce to

$$Ty_1 - Pl - \frac{wl^2}{2} = -\frac{P + wl}{n}\left\{\frac{e^{nl} - e^{-nl}}{e^{nl} + e^{-nl}}\right\} + \frac{w}{n^2}\left\{1 - \frac{2}{e^{nl} + e^{-nl}}\right\} = M_{max} \quad . \quad (28).$$

If $w = o$ this equation reduces to (19), as it evidently should. Also P may be made zero, leaving simply the uniform load and T.

IV. *Let the condition be as in Fig. 5, except reverse* T, *as in Fig. 6.* Then

$$\varepsilon I \frac{d^2y}{dx^2} = -Ty - Px - \frac{wx^2}{2} \quad . \quad . \quad (29).$$

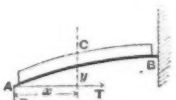


Figure 6.

Applying equation (15) for integrating this

$$-Ay - Bx - Dx^2 = \frac{\sqrt{AC + 4D^2}}{A} \sin(nx + C_1) - \frac{2D}{A}$$

where $A = \frac{T}{\varepsilon I}$ $B = \frac{P}{\varepsilon I}$ $D = \frac{w}{2\varepsilon I}$

To determine the constants of integration make $x = o$ for $y = o$, and eliminate the coefficient to 1st term, 2d member. Then make the tangent to the curve zero for $x = l$, and eliminate C_1, as was done in case II., we then get

$$-Ty - Px - \frac{wx^2}{2} = -\frac{P + wl}{n}\frac{\sin nx}{\cos nl} - \frac{w}{n^2}(1 - \cos.nx - \sin.nx \operatorname{tang} nl) = M \quad (30).$$

The load P may be + or −.

Making $x = l$ for the maximum moment, we get, by reduction,

$$-Ty_1 - Pl - \frac{wl^2}{2} = -\left(\frac{P + wl}{n} - \frac{w}{n^2}\operatorname{tang}\frac{nl}{2}\right) \operatorname{tang} nl = M_{max} \quad . \quad . \quad (31).$$

If $w = o$, this expression reduces to (24), as it obviously should. If $P = o$ we have simply the uniform load w, and the end thrust T.

V. *Let the beam be supported at both ends, carry a uniformly distributed load, and have a pull applied at both ends.*

The conditions are obviously equivalent in the two parts of Fig. 7, the latter being already solved in equations (27) and (28).

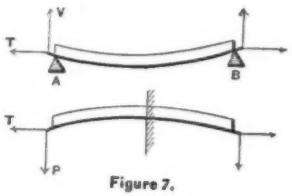


Figure 7.

The equation of moments for this figure is

$$\varepsilon I \frac{d^2y}{dx^2} = Ty - \frac{wlx}{2} + \frac{wx^2}{2} \quad . \quad (32).$$

since $V = \frac{wl}{2}$. Comparing with (27) we find the 1st member changed to (32) by changing P, . $-w$ and l there, to $\frac{wl}{2}$ w and $\frac{l}{2}$ here. By making the corresponding changes in 2d member of (27) we obtain for the 2d member of (32)

$$+\frac{w}{n^2}\left\{\frac{e^{n\left(\frac{l}{2} - x\right)} + e^{-n\left(\frac{l}{2} - x\right)}}{e^{n\frac{l}{2}} + e^{-n\frac{l}{2}}} - 1\right\} \quad (32).$$

l being the whole length, AB.

For the maximum moment $x=\frac{l}{2}$ and

$$Ty_1-\frac{wl^2}{8}=\frac{w}{n^2}\left\{\frac{2}{e^{n\frac{l}{2}}+e^{-n\frac{l}{2}}}-1\right\}$$

$$M_{max.} \quad . \quad . \quad . \quad (33).$$

VI. *Reverse* T; *otherwise take the case as in* V.

Hence reverse w, and take $P=\frac{wl}{2}$ in equations (30) and (31) and change l to $\frac{l}{2}$ and we obtain

$$-Ty-\frac{wlx}{2}+\frac{wx^2}{2}=$$

$$\frac{w}{n^2}\left(1-\cos nx-\sin nx \tang n\frac{l}{2}\right)=M \quad (34).$$

l being the whole length AB, and for the maximum moment $x=\frac{l}{2}$. $\therefore$

$$\therefore \quad -Ty_1-\frac{wl^2}{8}=-\frac{w}{n^2}\tang n\frac{l}{4}\tang n\frac{l}{2}$$

$$M_{max} \quad . \quad . \quad . \quad (35).$$

VII. *Let the beam be supported at its ends, with a load* Q *placed at equal distances from the ends, and have a tension* T *applied.*

Figure 8.

1st. Then for the part AC, the moments will be

$$\varepsilon I\frac{d^2y}{dx^2}=Ty-Px=Ty-Qx \quad . \quad . \quad (36),$$

comparing with eq. (13) we get

$$Ay+Bx=\frac{C_1}{2}e^{nx}-\frac{C}{2C_1A}e^{-nx} \quad . \quad (13).$$

where

$$A=\frac{T}{\varepsilon I}=n^2 \quad B=-\frac{P}{\varepsilon I} \text{ and } P=Q \quad . \quad (37).$$

For $x=o$, $y=o$ and

$$\frac{C}{2C_1A}=\frac{C_1}{2}$$

$$Ay+Bx=\frac{C_1}{2}\left(e^{nx}-e^{-nx}\right)$$

Differentiate and let $\frac{dy}{dx}=\tang i$ for $x=a$ $=AC=EG$, and

$$\frac{C_1}{2}=\frac{A\tang i+B}{\sqrt{A}\left(e^{na}+e^{-na}\right)}$$

$$\therefore \quad Ay+Bx=\frac{A\tang i+B}{\sqrt{A}}\left\{\frac{e^{nx}-e^{-nx}}{e^{na}+e^{-na}}\right\}$$

$$. \quad . \quad . \quad . \quad (39).$$

2d. For the part CB, the moments will be

$$\varepsilon I\frac{d^2y}{dx^2}=Ty+Q(x-a)-Px=Ty-Qa$$

where

$$A=\frac{T}{\varepsilon I}=n^2 \text{ and } F=-\frac{Qa}{\varepsilon I} \quad . \quad (40).$$

$$\therefore \quad Ay+F=\frac{C'}{2}e^{nx}-\frac{C_2}{2C'A}e^{-nx} \quad . \quad (13).$$

Now differentiate this and make $\frac{dy}{dx}=o$ for $x=\frac{l}{2}$ and

$$\frac{C_2}{2C'A}=-\frac{C'}{2}e^{nl}$$

Put this back in the same equation and make $\frac{dy}{dx}=\tang i$ for $x=a$, and

$$A\tang i=\frac{C'}{2}\left(e^{na}-e^{n(l-a)}\right)\sqrt{A}$$

This determines C' and C_2, and the values placed in the integral above give

$$Ay+F=\frac{A\tang i}{\sqrt{A}}\left\{\frac{e^{nx}+e^{n(l-x)}}{e^{na}-e^{n(l-a)}}\right\} \quad . \quad (41).$$

Now making the ordinates y, in the two equations, equal each other for the point C, where $x=a$ we obtain observing that $Ba=F$, (39)=(41), giving an expression by aid of which tang i is found. This value of tang i, put into eq. (39) or (41), gives the required expressions for the moments on the parts AC and BC, respectively.

Placing the parenthetical part of (39) equal L, and of (41) equal N, we get

$$A\tang i=-\frac{BL}{L-N} \quad . \quad . \quad (42).$$

The maximum moment on the whole beam will be found at the points C and E, directly under the equal loads Q, equidistant from the ends. This is obvious, from the fact that the moment due to P and Q for any part of CE is constant; but the moment of T, counter to that of P and Q, is least at C and E, for the part CE. As to AC, the moment is greatest at C.

Hence (39) or (41) will give the max. moment which is at $x=a$

$$\mathrm{T}y_1-\mathrm{Q}a=\frac{\mathrm{Q}}{2n}\,\frac{e^{n\frac{l}{2}}-e^{-n\frac{l}{2}}+e^{-n\left(\frac{l}{2}-2a\right)}-e^{n\left(\frac{l}{2}-2a\right)}}{e^{n\frac{l}{2}}+e^{-n\frac{l}{2}}} \quad (43).$$

$$=\mathrm{M}_{\max}.$$

If we make $a=o$ the moment (43) reduces to zero, as it evidently should, as it leaves the beam without load. Again, if $a=\frac{l}{2}$, the expression reduces to the same form as (19), P and l there, being equivalent to Q and $\frac{l}{2}$ here, a fact that verifies all complex and extended reductions of this case.

VIII. *Let this beam be conditioned the same as in* VII., *except reverse* T, *as shown in Fig. 9.*

The expression for the moment on AC is

$$\varepsilon\mathrm{I}\frac{d^2y}{dx^2}=-\mathrm{T}y-\mathrm{P}x,$$

where

$$\mathrm{A}=\frac{\mathrm{T}}{\varepsilon\mathrm{I}}=n^2 \qquad \mathrm{B}=\frac{\mathrm{P}}{\varepsilon\mathrm{I}}=\frac{\mathrm{Q}}{\varepsilon\mathrm{I}} \quad . \quad (44).$$

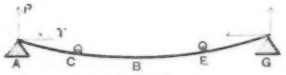


Figure 9.

Hence 1st by (15), making $x=o$ for $y=o$ for one constant, and $\frac{dy}{dx}=\text{tang } i$ at $x=a$ =AC= EG for the other constant.

$$-\mathrm{A}y-\mathrm{B}x=-(\sqrt{\mathrm{A}}\,\text{tang}\,i+\mathrm{B})\frac{\sin nx}{\cos na} \quad (45).$$

the eq. of the axis AC, and of moments for the same.

2d. For the part CB, moment=

$$\varepsilon\mathrm{I}\frac{d^2y}{dx^2}=-\mathrm{T}y-\mathrm{P}x+\mathrm{Q}(x-a)=-\mathrm{T}y-\mathrm{Q}a$$

where

$$\mathrm{A}=\frac{\mathrm{T}}{\varepsilon\mathrm{I}}=n, \quad \mathrm{F}=\frac{\mathrm{Q}a}{\varepsilon\mathrm{I}}=\frac{\mathrm{P}a}{\varepsilon\mathrm{I}}=\mathrm{B}a$$

Applying (15), first making $\frac{dy}{dx}=o$ for $x=\frac{l}{2}$ for one constant; then making the same equation =tang i for $x=a$, for the other, we get

$$-\mathrm{A}y-\mathrm{F}=-\frac{\sin\left(nx+\frac{\pi}{2}-n\frac{l}{2}\right)}{\cos\left(na+\frac{\pi}{2}-n\frac{l}{2}\right)}\sqrt{\mathrm{A}}\,\text{tang}\,i \quad . \quad . \quad . \quad (46).$$

Then equating the ordinates y_1 from (45) and (46) for $x=a$, observing that $\mathrm{B}a=\mathrm{F}$, we get the expression containing tang. i. Substituting it in (46) we get the general expression of moments for the part CE, also the equation of the curve of the axis of that part,

$$-\mathrm{T}y-\mathrm{Q}a=-\frac{\mathrm{Q}}{n}\,\frac{\text{tang}\,na.\sin\left(nx+\frac{\pi}{2}-nl\right)}{\sin\left\{\frac{\pi}{2}-n\left(\frac{l}{2}-a\right)\right\}-\text{tan}na.\cos\left\{\frac{\pi}{2}-n\left(\frac{l}{2}-a\right)\right\}}$$

$$=\mathrm{M} \quad . \quad . \quad . \quad (47).$$

For $x=a$ this becomes

$$-\frac{\mathrm{Q}}{n}\,\frac{\text{tang}\,na}{1-\text{tang}na\cot\left\{\frac{\pi}{2}-n\left(\frac{l}{2}-a\right)\right\}}$$

$$=\mathrm{M}_a \quad . \quad . \quad . \quad (48).$$

For $x=a=\frac{l}{2}$ we get

$$-\frac{\mathrm{Q}}{n}\text{tang}\,n\frac{l}{2}=\mathrm{M}_{\max} \quad . \quad . \quad (49).$$

(49) being greater than (48). This agrees with the indications of Fig. 9.

Equation (49) is the same as (24) as it evidently should.

If $a=o$ the moment reduces to zero, which the figure shows to be correct.

IX. *Let the beam be supported at the ends, be under tension T, and loaded with Q applied at any point.*

1st. For the part AC we get, origin of co-ordinates at A,

$$\varepsilon I\frac{d^2y}{dx^2}=Ty-Px$$

Figure 10.

Applying (13), observing that for $x=o$ $y=o$ for one constant: and that $\frac{dy}{dx}=$ tang i, for $x=a$ for the other, and reducing we get

$$Ty-Px=\frac{T.\text{tang}\,i-P}{n}\left\{\frac{e^{nx}-e^{-nx}}{e^{na}+e^{-na}}\right\} \quad (50).$$

From the figure $Pl=Q(l-a)$

$$\therefore \qquad P=Q\left(1-\frac{a}{l}\right) \quad . \quad . \quad . \quad (51).$$

If in (50) we make $a=\frac{l}{2}$ we have tang $i=o$, and introducing P, (50) reduces to the same as (19) and (43) for like values of a, and P.

2d. For the part BC with some reduction,

$$\varepsilon I\frac{d^2y}{dx^2}=Ty+\frac{Qa}{l}x-Qa$$

Applying (13) again, observing that for $x=l$ $y=o$, and $\frac{dy}{dx}=$tang i, for $x=a$, and reducing we get

$$Ty+\frac{Qa}{l}x-Qa=$$

$$\frac{T.\text{tang}\,i+Q-P}{n}\left\{\frac{e^{nx}-e^{n(2l-x)}}{e^{na}+e^{n(2l-a)}}\right\} \quad (52).$$

This equation reduces to the same as (50), (43) and (19) for like values of P, by making $a=\frac{l}{2}$; except (52) will have the negative sign, as it should, since its moment at C should oppose that of (50).

Now make $x=a$, and equate (50) and (52). This determines tang i. This can be restored to (50) and (52) for moments, or for equations of the curves of the axis of the parts of the beam. Thus the conditions of the beam are completely determined.

If we make the parenthetical part of (50) and (52)=L and N, respectively, we find, for $x=a$, in L and N,

$$\text{tang}\,i=\frac{Q}{n^2}\left(\frac{L}{L-N}-\frac{a}{l}\right) \quad . \quad . \quad (53).$$

For $a=\frac{l}{2}$; this reduces to o as it should.

In seeking the maximum moment we suspect that when Q is near A, or B at a particular point, the combined moment of T and P may possibly have a maximum between Q and the remote end, because that due to T varies as the ordinate y and P with x. But the mathematical test applied to (52) develops no such max. Hence the max. is always at the load Q, and can readily be found at $x=a$.

X. *Let the conditions be the same as in* IX. *except reverse* T, *or put the beam under compression, as in Fig. 11.*

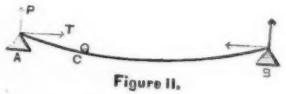


Figure 11.

1st. For part AC

$$\varepsilon I\frac{d^2y}{dx^2}=-Ty-Px$$

where

$$P=Q\frac{l-a}{l}$$

Integrating by aid of (15), making x and $y=o$ for one constant, and $\frac{dy}{dx}=$ tang i for the other, we obtain

$$-Ty-Px=-\frac{T\,\text{tang}\,i+P}{n}\frac{\sin nx}{\cos na} \quad . \quad (54).$$

2d. For the part BC we have

$$\varepsilon I\frac{d^2y}{dx^2}=-Ty-(P-Q)x-Qa$$

Applying (15) and make $x=l$ for $y=o$ for one constant, and $\frac{dy}{dx}=$tang i at $x=a$ for the other, and reducing we obtain

$$-Ty-(P-Q)x-Qa= \frac{T\tan g i+P-Q}{n}\cdot\frac{\sin n(l-x)}{\cos n(l-a)} \quad . \quad (55).$$

Equating 2d members of (54) and (55) for tang i at $x=a$, and then replacing it; the same equations become, for AC,

$$-Ty-Px= \frac{\frac{Q}{n}}{1+\tan g na\cot n(l-a)}\cdot\frac{\sin nx}{\cos na} \quad . \quad (56),$$

and for BC,

$$-Ty-(P-Q)x-Qa= -\frac{\frac{Q}{n}}{1+\tan g na\cot n(l-a)}\cdot\frac{\sin n(l-x)}{\cos n(l-a)} \quad (57)$$

which are equations of the axial curves and of moments.

These reduce to the same as (49) for $x=a=\frac{l}{2}$, also to (24) for proper value of l. Thus (56) becomes

$$\frac{Q}{2n}\tan g n\frac{l}{2}=M_{max} \quad . \quad (58).$$

the same as (48), observing that Q in (48) equals 2Q in the above.

In looking for the max. moment, we observe that when Q is near A, the moment will without question increase from A to C, because the moment arms of both T and P increase together. Also the moment of the reaction of the support B will increase from B to C. But the moment of T is greatest where the curve of the axis of the beam is lowest, and this is between Q and B. Now when T is great and P small, particularly when T is sufficient to hold the beam in the curved form, the maximum is plainly seen to be somewhat removed from Q towards the middle of beam, but in no case beyond the middle.

The 2d member of equation (57) is the expression for the moment of flexure of BC. Hence the moment varies along BC as the ordinates of a sinusoid the max. value being where sin. $n(l-x)=1$, or where $n(l-x')=\frac{\pi}{2}$. Hence

$$\therefore \quad \frac{x'}{l}=1-\frac{\pi}{2nl}$$

is the fractional part of the beam's length at which the moment *may* be a maximum, and where it will exist, in case BC has a less value. At $x=l$, or at B, the sinusoid starts, and overspans the beam length AB, as appears from the fact that when $x=o$, the value of (57) is still considerable, and positive. To find the springing points of the curve, place

$$\sin n(l-x)=o$$

giving

$$n(l-x)=o \text{ or}=\pi$$

Hence

$$x=l, \text{ or}=l-\frac{\pi}{n} \quad . \quad . \quad . \quad (59).$$

and the sinusoid is BED, for the beam AB, Fig. 12. The max. is at H when

$$AH=l-\frac{\pi}{2n} \quad . \quad . \quad . \quad (60).$$

equations (59) and (60) show that BD is twice BH. Suppose $n=.01$ and $l=200$. Then AH=43. and AD=−114.

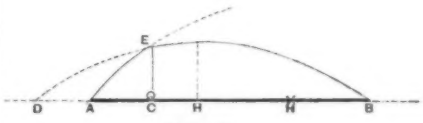


Figure 12.

The figure shows how the max. moment may occur at H when Q is at C, the curve AE being the sinusoid of eq. (56).

Similarly it may be shown that another point H′ exists where BH′=AH.

Now when Q is placed between H and H′, the max. moment is at Q, but it is at H or H′ when Q is outside those points.

XI. *Let the beam be fixed at one end, supported at the other, under compression T, and loaded with Q at any point.* Take the origin of co-ordinates at A, y positive downward and Ac=a. Then

1st for the part AC (Fig. 13)

$$EI\frac{d^2y}{dx^2}= -Ty-P(l-x)+Q(a-x)$$

$$=-Ty-(Q-P)x-(Pl-Qa)$$

Integrating by aid of (15) we get

$$-Ay-Bx-F=\frac{\sqrt{AC}}{A}\sin(nx-C_1)$$

where

$$A=\frac{T}{\varepsilon I}=n^2 \quad B=\frac{Q-P}{\varepsilon I} \quad y=\frac{Pl-Qa}{\varepsilon I}$$

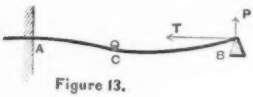


Figure 13.

For x and $y=o$ we get

$$\frac{\sqrt{C}}{n}=-\frac{F}{\sin C_1}$$

and for $\frac{dy}{dx}=o$ for $x=o$ we get

$$\cot C_1=\frac{B}{nF}$$

Hence

$$-Ay-Bx-F=-\frac{B}{n}\sin nx \\ -F\cos nx \quad . \quad (61).$$

and

$-A$ tang $i-B=-B\cos nx+nF\sin nx$

2d, For the part BC

$$\varepsilon I\frac{d^2y}{dx^2}=-Ty-P(l-x) \\ =-Ty+Px-Pl$$

Hence by (15)

$$-Ay-B'x-F'=\frac{\sqrt{C'}}{n}\sin(nx+C_1')$$

where

$$A=\frac{T}{\varepsilon I}=n^2,\ B'=-\frac{P}{\varepsilon I},\ F'=\frac{Pl}{\varepsilon I}$$

also

$$B'l+F'=o, B-B'=\frac{Q}{\varepsilon I} \quad a(B-B')=(F'-F)$$

For $x=l$, $y=o$ and

$$-B'l-F'=\frac{\sqrt{C'}}{n}\sin(nl+C_1')=o$$

$$\therefore \quad C_1'=-nl$$

$$\therefore -Ay-B'x-F'=\frac{\sqrt{C'}}{n}\sin n(x-l) \quad . \quad (62).$$

and

$$-A \text{ tang } i-B'=\sqrt{C'}\cos n(x-l)$$

Equating A tang i for $x=a$, from 1st and 2d and $\sqrt{C'}$ is determined, its value being

$$\sqrt{C'}=\frac{B-B'-B\cos na+nF\sin na}{\cos n(a-l)}$$

But in the present case P is as yet an unknown quantity, from the fact that Q is partly supported by the stiffness of the beam at A, and partly at B. We may, however, eliminate P by aid of the condition that the ordinates y from 1st and 2d are equal at $x=a$.

Equating the ordinates y, we find, after much reduction,

$$\frac{P}{Q}=\frac{\sin n(l-a)+na\cos nl-\sin nl}{nl\cos nl-\sin nl}=q$$

or $P=Qq$. . . . (63).

If $a=l$, $P=Q$; and if $a=o$, $P=o$; which are obviously correct.

The equation of the curve of the axis of the beam for AC, also the moment of flexure, will be

$$-Ty-Q\Big(q(l-x)-(a-x)\Big)= \\ -Q\Big((ql-a)\cos nx-\frac{q-1}{n}\sin nx\Big) \quad (64).$$

Similarly we have for BC

$$-Ty-Qq(l-x)= \\ -\frac{Q}{n}\Big(1-(1-q)\cos na+n(ql-a)\sin na\Big) \\ \frac{\sin n(l-x)}{\cos n(l-a)} \quad . \quad . \quad . \quad (65).$$

An inspection of the figure shows that there will always be a point of contra flexure in the beam, or where the moment of flexure will be zero.

Trying (64) for this point, placing the 2d number $= o$, we obtain

$$(1-q(\text{tang } nx=n(a-ql)$$

or

$$\text{tang } nx=na-\frac{\left(1-q\frac{l}{a}\right)}{1-q}$$

in which x locates the point of centro-flexure, and a the load. There is most doubt as to the relation of x and a when these quantities are small. When very small the tangent approximates the arc, when the fraction to na is less than 1, which makes x less than a.

Trying (65), the 2d number $=o$ when sin $n(l-x)=o$, or $n(l-x)=o$, π, 2π, &c. But $x=l$ when $n(l-x)=o$

$$x=l-\frac{\pi}{n} \text{ when } n(l-x)=\pi$$

But according to eq. (59) and Fig. 12, x in (65) has no value within the limits of the beam for a varying from o to l.

Hence we conclude that the point of contrary flexure is always between the load Q, and the fixed end of the beam, and it is difficult to tell which is the greater except in particular cases.

The point of maximum moment is to be found where the 2d member of (65) is a maximum. This occurs where

$$\sin n(l-x)=1 \text{ or } n(l-x)=\frac{\pi}{2}$$

$$\therefore \quad x=l-\frac{\pi}{2n} \quad . \quad . \quad . \quad (60).$$

if we ignore a. But considering a, it appears that the max. moment of flexure is always at Q, except when a is =, or less than x in (60); conditions identical with case X, as regards the one point H, Fig. 12.

Either member of (64) makes the moment at A where x and $y=o$

$$=-Q(ql-a) \quad . \quad . \quad . \quad (66).$$

But where $x=a$, the other limit of x for this expression, the moment is

$$-Ty-Qq(l-a)=$$

$$-\frac{Q}{n}\Big(n(ql-a)\cos na-(q-1)\sin na\,(67).$$

and it is difficult to tell which is the greater, except in particular cases.

An inspection of figure 13 shows that if the compression T can be great enough to hold the beam in a curve while Q is zero, the force P will be reversed. Now, if Q be given some real positive value increasing from zero up, it will eventually make $P=o$. But by (63), when $P=o$, $q=o$. Hence to find the relation between T and Q for this, make $q=o$ in (64) and (65.)

XII. *Take the conditions as in* XI. *except change* T *to tension.*

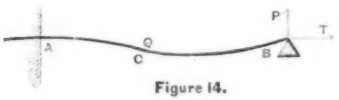


Figure 14.

1st. For the part AC, origin of co-ordinates at A, and y positive downward,

$$\varepsilon I\frac{d^2y}{dx^2}=+Ty+Q(a-x)-P(l-x)$$

$$=Py-(Q-P)x+(Qa-Pl)$$

Integrating by aid of (13) and determining the constants by the conditions $x=o$, for $y=o$, and $\frac{dy}{dx}=o$ for $x=o$ we get an equation of the curve of the axis of the beam AC, and also the moment of flexure

$$Ty-(Q-P)x-(Qa-Pl)=$$

$$\frac{Qa-Pl}{2}\Big(e^{nx}+e^{-nx}\Big)-$$

$$\frac{Q-P}{2n}\Big(e^{nx}-e^{-nx}\Big)=M \quad . \quad . \quad . \quad (68).$$

But P is here an unknown quantity, and is to be found as it was in XI.

2d. For BC

$$\varepsilon I\frac{d^2y}{dx^2}=Ty-P(l-x)$$

$$=Ty+Px-Pl$$

which may be integrated by (13), for $x=l$, $y=o$; giving value to one constant. Then place tang i, for the point C equal the same from (68), making known the second constant. Then equate the ordinates y for the point C, by which to determine P. The work is too tedious to detail here, but the result is

$$\frac{P}{Q}=$$

$$\frac{e^{-nl}-e^{nl}-e^{-n(l-a)}+e^{n(l-a)}+na\left(e^{nl}+e^{-nl}\right)}{e^{-nl}-e^{nl}+nl\left(e^{nl}+e^{-nl}\right)}$$

$$. \quad . \quad . \quad (69).$$

When $a=l$ $P=Q$, and when $a=o$, $P=O$; which are correct for these points and verify the result.

The maximum moment of strain for the whole beam, and under all conditions is probably at A, as it is at this point for the case that $T=o$. The probability seems to become a certainty from the fact that when T exists, its moment, which is counter to that of Q, is greatest where the deflection is greatest, or at intermediate points.

XIII. *Let the beam be fixed at both ends, be under tension T and have a load Q at the middle, and a uniformly distributed load.*

$$\varepsilon I\frac{d^2y}{dx^2}=Ty+\frac{wx^2}{2}-Px+P_1(r+x)$$

$$=Ty+\frac{wx^2}{2}+(P_1-P)x+P_1r$$

where $P=P+\frac{wl}{2}+\frac{Q}{2}$

Integrating by aid of (13), and observing that for $x=o$, $y=o$, and that $\frac{dy}{dx}=o$, for $x=o$ and also for $x=\frac{l}{2}$; and we get,

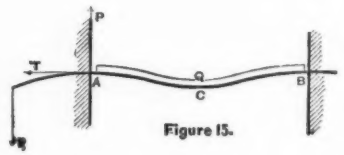


Figure 15.

after reduction, the general equation of moments and of the axis of beam

$$\mathrm{T}y+\frac{wx^2}{2}-\frac{wl+\mathrm{Q}}{2}x+\mathrm{P}_1r=\frac{wl+\mathrm{Q}}{4n}\left(\frac{e^{-nx}-e^{nx}}{e^{\frac{nl}{2}}-e^{-\frac{nl}{2}}}-\frac{2-\frac{2wl}{wl+\mathrm{Q}}}{e^{\frac{nl}{2}}-e^{-\frac{nl}{2}}}\left(e^{\frac{nl}{2}}-e^{-\frac{nl}{2}}\right)\right)$$

$$-\frac{w}{n^2}=\mathrm{M} \quad . \quad . \quad . \quad (70).$$

In case the load is only Q, make w $=o$, or if we have only the uniform load, make Q $=o$ and the resulting expressions will give the moment of flexure at any point in the length of the beam.

At the point A, the moment is a max. and formed by making $x=o$, and $y=o$. Hence, as $\mathrm{P}_1r=$moment at A, we have,

$$\mathrm{P}_1r=\frac{\frac{wl}{n}}{e^{\frac{nl}{2}}-e^{-\frac{nl}{2}}}+\frac{wl+\mathrm{Q}}{2n}\cdot\frac{e^{\frac{nl}{4}}-e^{-\frac{nl}{4}}}{e^{\frac{nl}{4}}+e^{-\frac{nl}{4}}}-\frac{w}{n^2}=\mathrm{M}_{max} \quad . \quad . \quad (71).$$

When $w=o$, (71) becomes

$$\mathrm{P}_1r=\frac{\mathrm{Q}}{2n}\cdot\frac{e^{\frac{nl}{4}}-e^{-\frac{nl}{4}}}{e^{\frac{nl}{4}}+e^{-\frac{nl}{4}}}=\mathrm{M}_{max} \quad . \quad (72).$$

But when $\mathrm{Q}=o$, (71) becomes

$$\mathrm{P}_1r=\frac{wl}{2n}\cdot\frac{e^{\frac{nl}{2}}+e^{-\frac{nl}{2}}}{e^{\frac{nl}{2}}-e^{-\frac{nl}{2}}}-\frac{w}{n^2}=\mathrm{M}_{max} \quad . \quad . \quad (73).$$

At the middle of the beam $x=\frac{l}{2}$ and the moment, for $w=o$, is the same as (72) except the sign is contrary.

But for $\mathrm{Q}=o$; instead of (73) we have

$$\frac{\frac{wl}{n}}{e^{\frac{nl}{2}}-e^{-\frac{nl}{2}}}-\frac{w}{n^2}=\mathrm{M} \quad . \quad . \quad . \quad (74).$$

The four last equations give the moments most likely to be needed, and the value of P_1r put in (70) gives us the equation of the curve of AQ and BQ is like it.

XIV. *Take the case as in* XIII., *except change* T *to compression.*

$$\varepsilon\mathrm{I}\frac{d^2y}{dx^2}=-\mathrm{T}y-\mathrm{P}x+\frac{wx^2}{2}+\mathrm{P}_1(r+x)$$

$$=-\mathrm{T}y-(\mathrm{P}-\mathrm{P}_1)x+\frac{wx^2}{2}+\mathrm{P}_1r$$

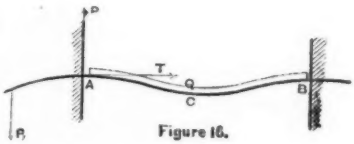


Figure 16.

Integrating by aid of (15), and observing that for $x=o$, $y=o$; and that $\frac{dy}{dx}=o$ for $x=o$ and for $x=\frac{l}{2}$; we obtain

$$-\mathrm{T}y-\frac{wl+\mathrm{Q}}{2}x+\frac{w}{2}x^2+\mathrm{P}_1r=$$

$$=-\frac{wl+\mathrm{Q}}{2n}\left(\sin nx+\cot n\frac{l}{2}\cos nx\right)+\frac{\mathrm{Q}}{2n}\cdot\frac{\cos nx}{\sin n\frac{l}{2}}+\frac{w}{n^2}=\mathrm{M} \quad . \quad . \quad (75).$$

At A, x and $y=o$, and

$$\mathrm{P}_1r=-\frac{wl+\mathrm{Q}}{2n}\cot n\frac{l}{2}+\frac{\mathrm{Q}}{2n}\cdot\frac{1}{\sin n\frac{l}{2}}+\frac{w}{n^2}=\mathrm{M}_{max} \quad . \quad . \quad . \quad (76).$$

When $w=o$ (76), becomes

$$\frac{Q}{2n}\text{tang } n\frac{l}{4}=M_{max} \quad . \quad . \quad . \quad . \quad (77).$$

essentially the same as (58).

But when $Q=o$ in (76), we have

$$P_1r=-\frac{wl}{2n}\cot n\frac{l}{2}+\frac{w}{n^2}=M_{max} \quad . \quad . \quad (78).$$

This is the same as at B, where $x=l$. Q still $=o$

At the middle of the beam $x=\frac{l}{2}$, and the moment for $w=o$, is the same as (77) except the sign is contrary. But for $Q=o$, instead of (78).

$$-\frac{wl}{2n\sin n\frac{l}{2}}+\frac{w}{n^2}=M \quad . \quad . \quad . \quad (79).$$

Thus the most needed moments are obtained, and the equation of the elastic axis of the beam is fully given, P_1r, in (75), being made known by (76).

CHRONOGRAPH FOR ENGINEERING PURPOSES, WITH THE HIPP ESCAPEMENT.

By W. R. ECKART, C.E.

Read at the Philadelphia Session, Am. Society of Mechanical Engineers, April, 1882.

HAVING for a number of years felt the need of some instrument for measuring and recording the velocity of Pumping machinery which I have been brought in contact with, professionally, at the deep mines on the Comstock Lode, where the irregularity due to long and heavy pump rods as well as other masses in motion were greatly felt, I was forcibly impressed with an article by Robert Briggs, C.E. (Journal Franklin Institute, 1877, Page 89), describing the "Hipp Escapement" and its adaptability to the purposes I desired.

I corresponded with that gentleman, and he had constructed for me in Philadelphia, the escapement and driving gear now used (for a detailed account of the Hipp escapement, I must refer to his paper on that subject). But the revolving drum and other arranged parts of the instrument had to be changed, as no way of recording the curves of motion on paper could be used that produced perceptible friction (such as pencils or ink); and on account of the exceeding sensitiveness of the controlling spring of the escapement, great care was required in securing a perfect balance of the revolving drums with ease of motion, without the use of heavy driving weights; in other words, all parts of the instrument had to be made as sensitive as possible, so as to require the least possible weights to produce the desired motion.

In the start numerous failures had to be put up with for not paying attention to these points of construction, and even now, if the recording paper is not properly put on the revolving drum, a slight excess of weight on one side of the drum, such as that due to lapping the paper, will produce a perceptible change of sound from the escapement spring, indicating an acceleration or retardation of motion, according as the excess is on the descending or ascending side of the drum. In covering the drum with paper I have found it desirable to cut the sheets some $\frac{3}{8}$ or $\frac{1}{4}$ inch less than the exact circumference of the drum, and to unite the edges by means of a strip of paper mucilaged and lapping slightly on each edge. The whole joint is then thinned down with fine sand paper to equal weight and smoothness—the whole sheet is covered with a coating of lamp black from a suitable hand lamp, and is then ready to receive the curve of motion.

The tracers, both for recording seconds as well as the velocity curve of the engine, are made of flat strips of spring steel, the axis of each being pivoted at the end on adjustable screw centers to prevent lost motion. By means of a small steel wire and weight extending to the opposite side, the tracers can be made to bear as lightly as desirable on the paper, and when properly adjusted the pressure is only sufficient to remove the lamp black without touching the paper, thereby leaving a fine white line on the dark back ground with the least possible interruption of

motion. The whole is permanently set by dipping the face in a thin solution of shellac.

Instead of using a pendulum for producing (through an electro-magnet), the marks spacing seconds on the paper, which is the usual device, some other method was found necessary that would admit of greater compactness and portability; for the chronograph was to be used, not only on the surface where the pumping engines were situated, but it had to be adapted to underground use. And those who are acquainted with the general arrangement of a deep mine pumping compartment, especially on the Comstock, where the air is heavily surcharged with steam from the excessively hot water of the mines, know, that the difficulties to be overcome were not slight, and compactness was absolutely necessary, as the whole instrument when in use, had, not only to be protected from the steam and dripping water, but had to be set up in such cramped spaces as could be found available, without any further preparations, and the time for adjusting the instrument as a whole ready for use, had, in all cases to be as limited as possible, as the temperature in which I was obliged to take diagrams sometimes reached 110°.

After numerous experiments, the use of a chronoscope (or timer), such as is to be had for timing horse races, was made to give satisfactory results. (See Fig. 1.) The method adopted was as follows:—A stand or base plate upon which the timer was placed had a brass stanchion suspending a fine platinum wire directly over the second hand; this wire, when at rest, bore on a piece of platinum inserted in a rubber insulator projecting from the stanchion, each of these wires being connected in the usual manner through the electro-magnet on the chronograph to a two-cell battery. A circuit was always formed, except when the hand of the timer, revolving once every second, swings the suspended wire free from its metal bearing at the apex of the triangular notch cut in the rubber guide-piece; as contact was broken every revolution of the second hand, the armature of the electro-magnet recorded the same by a side movement of the steel tracer resting on the prepared paper of the drum.

The suspending wire was made adjustable in various directions to suit the second hand, and when once adjusted the whole instrument was covered with a glass case protecting it from moisture, and could be transported and used with rapidity and without further difficulty.

Mr Briggs states (in his paper above referred to) that Prof. Hilgard used a chronoscope for the Navy Ordnance Department, in which the second marks were 30 inches apart. I have found no trouble in speeding the revolving drum of 6″ diameter, until the second marks were 20 inches apart, but for practical use, a length of three to ten inches (depending somewhat on the engine speed), was all that was desired, and by use of a standard steel scale with the inch divided into hundredths, changes of motion taking place in the $\frac{1}{1000}$ part of a second, were easily read and recorded without trouble, and the crossing of lines due to the too frequent revolution of the recording drum during one stroke of the engine was avoided. The use of the small electro magnet,—on the tracer carriage, to raise for an instant the tracing pointer off of the drum at any desired point, was found necessary in determining the effects of elasticity in the interruption and variation of motion, where a *long* line of pump rods was used, and was also found useful in fixing, positively, the exact point of closing or opening of the steam valves of the engine, independent of all reference to the indicator cards taken.

Two drawings giving different views of the chronograph as constructed and used, are attached to this article, exhibiting details of construction to complete what otherwise might be considered a defetive description of the instrument.

It may not be out of place here to state that the instrument has been successfully applied to several of the different types of large pumping engines found on the Comstock Lode, such as Direct-Acting Fly-Wheel Engines, Geared Pumping Engines, and the "Davy Engines;" it has also been used to determine the motion and relative motion of pump rods, and pumps some 2500 feet below the surface engine driving same, and at intermediate points. The results are exceedingly interesting and instructive, and as numerous indicator cards were taken from the engines and pumps sim-

ultaneously with the motion diagrams, nearly all conditions of motion and power, during the time under consideration, were definitely determined, and may hereafter form the subject of other papers when time will permit.

Some very important results of the elasticity of long pump rods are clearly set forth in one case: A rod at a point 1800 feet below the surface showed a positive pause, while the engine driving it was nearly at its point of maximum motion, and pumps attached to the rods may have, and do have strokes in excess of, or deficient to the *stroke of engine driving same*, and to an *important extent*. Hence, I think, it can be definitely stated that any consideration of motion of pumps, or discharge capacity of same, driven by a long line of pump rods based upon the motion or stroke of a surface engine alone, will in no way be even approximate, unless the elasticity and effects of counter-balancing by balance bobs on that elasticity, is also considered.

The effects of different degrees of compression upon the engines and motion of the pump rods in passing the centers have been considered, and the diagrams clearly show the importance of considering it in connection with the strength of the rods and balance bobs.

My latest use of the instrument in conjunction with an engine test, has been to determine, if possible, the rate of condensation of steam per second, in the steam cylinders of a pumping engine, where the change of motion due to each fractional part of the stroke was determined. Also, a ten hour experiment trial, to show the economy of compression, as compared with a ten-hour trial of the same engine on the succeeding day where no compression was used, (otherwise all conditions being similar), has been made, when changes of velocity of piston were determined by the chronograph. I hope sometime to make public the results of these observations for the use and criticism of those interested, after the labor of working them up and tabulating them is completed.

While it is well known that a Committee of the British Association applied a chronograph of Morin's type in 1843 4, to the determination of the velocity of piston for a Cornish Pump Engine, I believe there was no application of the instrument to the rods below ground, and, from published records at my command, I am led to believe that this is the first application of a chronograph of sensitive construction ever made to pit work, and the other purposes so briefly mentioned.

Lettered Reference to Figures 1 and 2 of the Instrument.

CC—Cast iron base plate, covered with sheet brass, upon which the mechanism is secured.

B—Metal frame containing gearing for driving drum A, and escapement wheel *b*; motion communicated by means of adjustable weights, D.

AA—Light brass drum, accurately balanced, revolving on friction rollers 8, 8, at both ends.

ff—Parallel guide bars upon which the tracing point h_0 and its carriage travel back and forth, receiving motion in one direction from the engine or other moving parts, through the cord P, passing between the bars *f*, and attached to the tracing carriage—the return motion is derived from a coiled spring in the spring drum C.

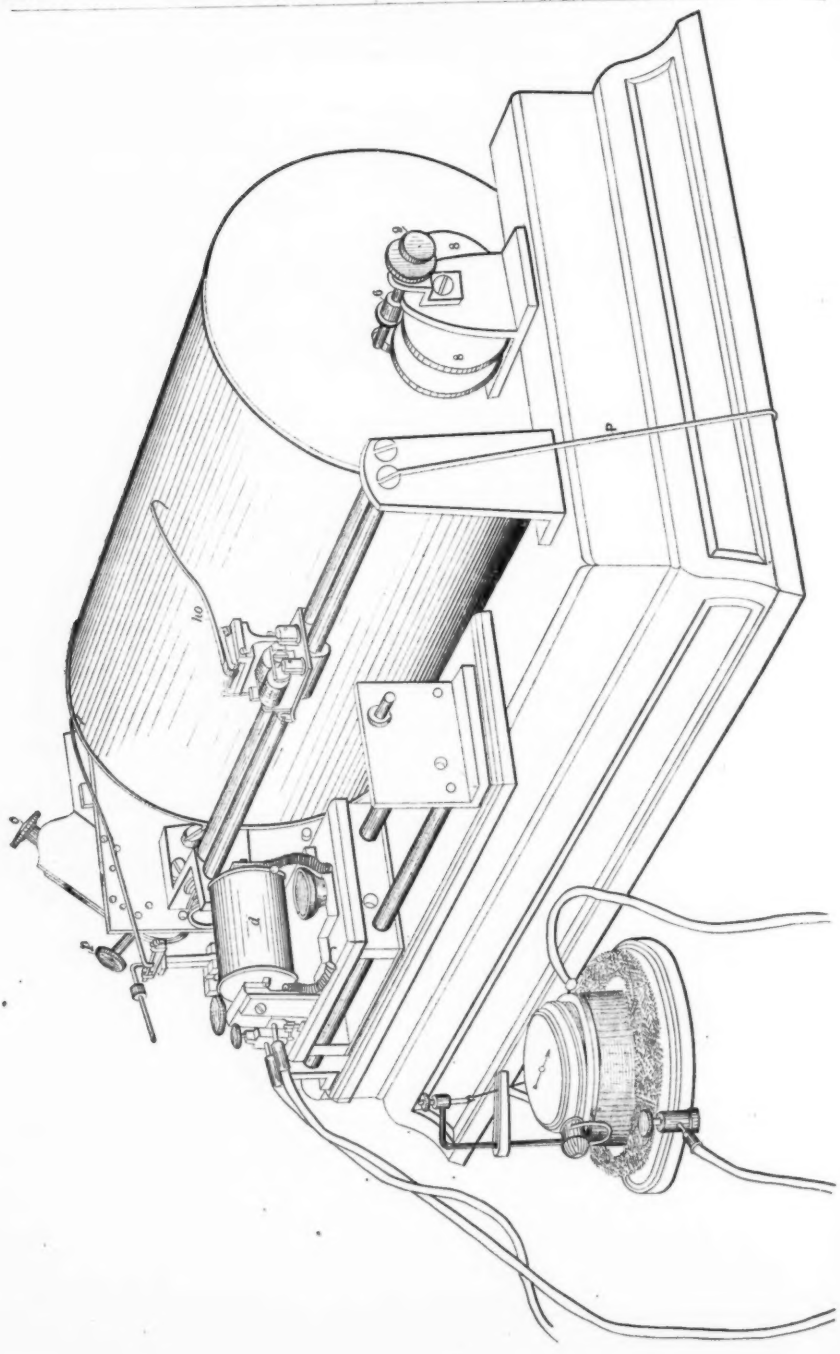
ee—Small electro-magnets on tracing carriage for raising the tracing point h_0 off of the paper and replacing it at any desired point to be especially observed.

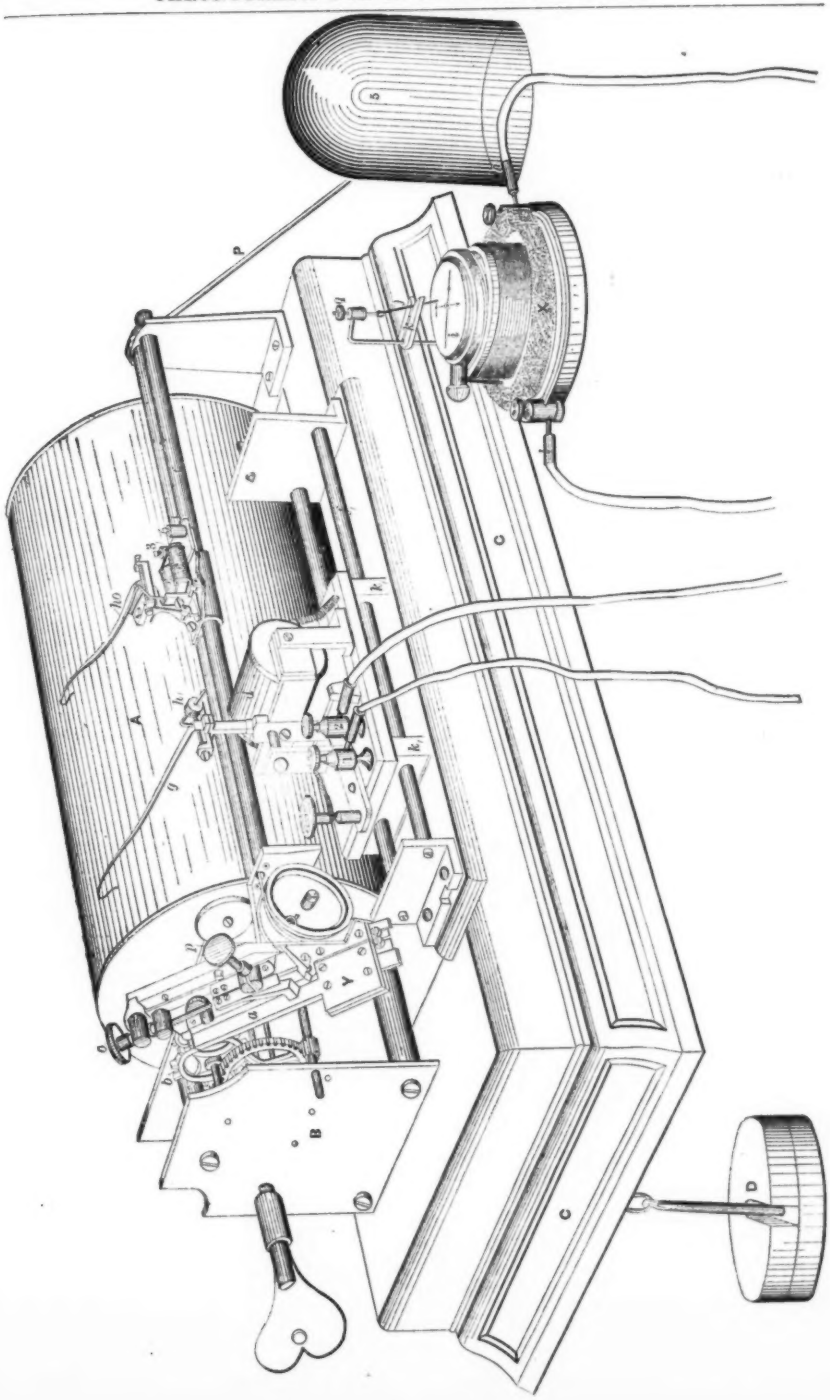
d—Electro-magnets on separate carriage *kk*, adjustable on parallel bars *f*, operating the steel tracing point *g*, attached to the armature of *d*, for the purpose of recording seconds on the margin of the paper or at other parts of same as required.

i—Chronoscope or watch supported on frame X, the second hand of which swings the light platinum wire J, breaking contact with the insulated wire *k*, thereby breaking circuit with *d* and recording seconds through the tracing point *g* on the paper.

q—Adjusting screw for the wire J.

a—Steel spring of escapement. This spring is securely clamped in Y, its flexibility being controlled to a certain extent by means of the thumb-screws *o* and *p*.

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REPORTS OF ENGINEERING SOCIETIES.

ENGINEERS' CLUB OF PHILADELPHIA, March 18th, 1882.

President Rudolph Hering presented notes on the Resistance to Traction on Streets, giving results compiled from various authors who had experimented on the subject. Resistance varies nearly as the weight, being great for heavy loads and almost nothing for light pleasure carriages. It increases on paved streets with the velocity and as the diameter of the wheels become less. The width of tire has little influence on hard and smooth roads, especially for light loads, while it has considerable influence on soft and rough roads, particularly when the load is heavy. The most economical conditions for traction, therefore, are a hard and smooth surface, large wheels and broad tires; the latter for heavy loads drawn on rough roads. To draw a load on sand requires a power equal to $\frac{1}{5}$ its weight, on ordinary earth $\frac{1}{10}$, on hard clay $\frac{1}{20}$, on ordinary cobble stones $\frac{1}{15}$, on good cobble pavements $\frac{1}{30}$, on ordinary Belgian blocks $\frac{1}{40}$, on London blocks $\frac{1}{60}$, on asphalt $\frac{1}{120}$, and on iron rails $\frac{1}{300}$ of the load.

The economy in horse power obtained by using the hardest and smoothest roads is clearly shown. If one horse can just draw a load on a level, over iron rails, it will take $1\frac{2}{3}$ horse to draw it over asphalt, $3\frac{1}{3}$ over the best Belgian, 5 over ordinary Belgian, 7 over a good cobble stone, 13 over a bad cobble stone, 20 over an ordinary earth road, and 40 over a sandy road.

Mr. D. H. Shedaker exhibited a large and very complete work on "The Art of Surveying," by John Wing, published in 1699, and presented Report of Mr. Heber S. Thompson, Engineer Girard Estate, upon the extinguishment of the fire at Kehley's Run Colliery.

Mr. W. S. Auchincloss exhibited his averaging machine, which consists of a stand with two uprights which support a rectangular pan 29″ long and about 10″ wide. The edges of this pan are formed of tubes, which slide through the bearings and enclose rods forming counterweights. These rods are connected by pulleys with the pan so that, when it is moved in one direction, they move in the other and so preserve the equilibrim.

The pan is divided into equal grooves at right angles to its length.

Paper scales, graduated for various uses, accompany the machine, and the adjustment is so accurate that the absence of a scale, which forms part of the balanced weight of the pan, throws the machine entirely out of balance. A convenient series of weights is provided to compose the quantities to be averaged. We place these in the grooves opposite their appropriate points on the scale, slide the pan until in equilibrium and read the average at once from the scale, at the point of support.

This machine was designed especially to average commercial accounts, and can solve one hundred accounts per hour and work both sides of ledger at once; but it is also adapted to ascertain average haul of earth, speed of pulleys, &c.

The Secretary presented a description of Defenbach's rail joint.

AMERICAN SOCIETY OF CIVIL ENGINEERS.—The Society met at its House in 23d Street, New York, Wednesday Evening, April 5th. President Ashbel Welch in the chair.

Arrangements were made for the Annual Convention of the Society to be held in Washington, May 16th, prox., and succeeding days. The introduction of a bill in Congress was announced for establishing a Commission composed of persons skilled in the investigation, production and use of Metallic Substances and other Structural Materials. The great importance of the speedy passage of this bill to the future safe and economical construction of Bridges, Roofs, Floors, Iron or Steel Ships, Ordnance and Armor and all structures in which metal is extensively used was forcibly presented.

A paper by A. P. Boller, M. Am. Soc. C.E., on the Mode of Underpinning adopted for the Croton Lake Bridge, New York City, and Northern R. R. during the Repairs to the Masonry Piers, was read by the Secretary. This Bridge was a single track, wrought iron, deck structure, in three spans of 160 feet each, with skeleton wrought iron piers or towers springing from blocks of masonry. The water was 30 feet in depth. These towers had four legs and thus concentrated all the weight upon the four corners of the masonry. This masonry had been built ten years before by another company. It rested below low water upon timber cribs. It was tested by loading with stone before building the iron bridge without showing improper settlement. The erection of the bridge towers and the use of the bridge soon developed the fact that the masonry could not stand the weight upon its corners and it became necessary to rebuild it. The towers being continuous frame works with spreading legs made it practicable to build inside of them a subsidiary wooden tower with perpendicular legs. This was done, the bottom wood sills being placed so as to admit the introduction of weight 20 ton hydraulic jacks. Two minutes work with the jacks lifted the towers and adjoining spans bodily. They were then supported upon 15-in. rolled beams, 200 lbs. to the yard, placed in pairs, resting on the inner side upon timbers distributing the weight upon the masonry, and on the outer sides on timber supports built up from the original crib work. The defective masonry was then taken out and rebuilt. One half hour sufficed to raise the structure, throw the weight upon the cross girders and resume traffic.

No train was delayed on its schedule time.

The author criticises severely the character of the old masonry.

The subject of the overflow of the Mississippi was also discussed.

ENGINEERING NOTES.

THE PANAMA CANAL.—The November rains delayed the progress of the works, and the accounts now received by mail do not give much of interest as the result of the labors of

that month. The houses at Colon for workmen and superintendents and their wives are making progress, and some are completed, as is the main body of the hospital. The company has purchased another large piece of ground in the island of Mauzainlo, for the reception of machines, stores, &c., between their arrival by sea and despatch by rail. The steam sloop Nina, a flat-bottomed lighter, and three barges, have been launched at Colon. The third excavator and two steam windlasses have been set up, and rails laid down temporarily on the newly purchased land in connection with the railways at Folks river. Similar preparatory work has been carried on at other stations, and Lesseps City has made progress. New villages are being marked out at Gamboa and Emperador; the old village at the former place will be submerged when the great artificial lake is formed. The San Pablo sounding has only gone 20 feet deep as yet, and has found a superficial layer of vegetable soil, under which is a soft argillacious tufa Opposite Gamboa, hard rock has been met with at a depth of 10 feet, and as its surface is sharply inclined soundings are being made to ascertain its slope. At the Cerro Obispo a very hard black rock has been found at 20 feet, which is believed to be doleritic. Meteorological and hydrographical observations have been carefully carried on, but no remarkable phenomena have occurred. The fall of rain in the interior of the isthmus is not so great as it is at Colon, and it is still less at Panama. It is supposed that the Cordilleras catch some of the rain clouds coming from the north, and cause them to discharge upon the Atlantic coast. The temperature during the month of November has varied within the following limits: Colon, maximum 31 deg. 5 min. Cent., minimum 20 deg. 6 min.; Gamboa, maximum 37 deg. 5 min., minimum 20 deg.; Island of Naos (Panama) maximum 33 deg. 5 min., minimum, 22 deg.

THE CANAL FROM THE ATLANTIC TO THE MEDITERRANEAN.—The Commission appointed by the French Government to investigate the plan for this canal, submitted by the surveying company presided over by M. Duclerc, has sent in an indecisive report. The proposed canal would be about 270 miles long, connecting Bordeaux and Narbonne with Toulouse as one of its ports. Its highest point would be 500 feet above the level of the sea. It would be supplied with water from the River Garonne and other minor sources, and would admit of the passage of ships of war. Its military advantages are those which appear most obvious; but its supporters also claim that it would be useful to agriculture by enabling the vine to be cultivated along its course. They expect a considerable revenue from irrigation and water-power rents, besides the ordinary tolls. The majority of the Commission estimate the total cost of construction at £56,666,160; and while considering the work practicable, decline to give an opinion as to whether or not it would be worth the expense. The minority assert that the construction would be exceptionally difficult, and that the canal when made would be of little or no use. The Commission concludes its report by advising that more detailed inquiries should be made into the agricultural and commercial conditions of the district through which the proposed canal would pass, and its probable effect upon them.

PROPOSED TUNNEL BETWEEN ITALY AND SICILY.—A project for a tunnel between Reggio and Messina has been presented to the Minister of Public Works by the "Societa Veneta di Publicha Construzioni." The author of this project is Signor Federico Gabelli. The total length of this tunnel will be 13,200 meters, including the inclined approaches, or 1,000 meters longer than the Mont Cenis Tunnel. The maximum depth of water over the proposed tunnel will be 110 meters, the ends of which, at this place, would be 35 meters below the bottom of the sea. The direction of the submarine portion of the undertaking will be from S.E. to N.W., between the Punta Del Pizzo and Sta. Agata. The inclined approaches, 4,500 meters in length, will run parallel with the shore for a certain distance, and then, with a curve of 350 meters radius, join the tunnel under the straits, which will be 4,200 meters long, or rather more than 2½ miles. The gradient of the inclines is fixed at 2½ per 100, or the same as that on the line from Turin to Genoa at the Giovi Tunnel. The submarine portion will have a fall of ½ per 1,000 from the center towards the shore ends, in order that the filtrations of water may drain and be pumped out by engines, which will be fixed at the vertical shaft from which the tunnel will be driven. From a geological examination of the locality, it would appear that the bottom of the straits consist of crystalline rocks, such as granite, gneiss, and mica schist. The quatertiary formation that covers the crystalline rocks, both on the Sicilian and Calabrian coasts, is not supposed to run deep, and should fissures occur in the older formations, through which it is proposed to drive the tunnel, they are probably filled up with clay or mud, so that there will be no fear of water finding its way into the tunnel. According to Signor Gabelli, the cost of the undertaking will not exceed 65 millions of lire (£2,600,000), and could be completed in six years.

CHANNEL TUNNEL.—At a meeting of the Submarine Continental Railway Company, held on the 20th January, 1882, Colonel Beaumont described the process of making the tunnel, by means of machinery designed by himself and Captain English. He said, "Captain English's and my own machine is now heading at the rate of 12 yards per day of seventeen hours. We have every confidence that the machine which will next be put into the heading will drive at the rate of 1 yard of the heading per hour. If you have the same thing done on the French side, that will be 2 yards per hour, or in round numbers, 50 yards per day. . . The dirt that is cut by the machine is delivered in the wagons, so that this advance is actually got by the manual efforts of two men only. One man is employed at the

face of the machine, and another man behind, driving it, and these two represent the only manual labor employed at the machine. The ventilation, which is of course a very important matter, and an absolute *sine qua non* in connection with the question of traffic through the tunnel, so far as the construction of the works is concerned, is provided by the air which is necessary to work the boring machine itself. . . . The amount of air which is required for working the machine is quite sufficient to keep the headings perfectly ventilated. . . Compressed air is now in such a position that it becomes quite a measurable quantity. You can estimate the amount of coal you have to burn to move a given amount of dirt. . . By the use of compressed air, and burning one pound of coal, you will move three tons a mile on a railway."

GREAT improvements and additions have been recently completed in the drainage of Walthamstow, under the direction of Mr G. B. Gerram, A.M.I.C.E. The defects in the sewerage were chiefly in the private streets. One of the principal works that have been executed consisted in providing sewers for draining Higham Hill, where before cesspools existed, which overflowed into the brook. The level of the main northern sewer was above that of the brook, and this has been got over by building a new invert, and raising the road some 4ft. 6in. in height, thus making the approach to Higham Hill much easier and more convenient The culvert is 8 feet in width and 4 feet high, the invert being curved and laid with Staffordshire blue bricks on edge, in cement, on a bed of concrete. This is covered over with iron girders, and jack arches covered with concrete. The sewer recently laid is over six miles in length, and over 28,000 cubic yards of earth have been excavated. Junction pipes are laid at intervals of 30 feet and 40 feet, so as to avoid any necessity of breaking the sewers to make any connection therewith. The works have been executed by Messrs. Currall and Lewis, contractors of Birmingham. The construction of the surface-water drains has prevented any flooding of the sewage farm during the recent extraordinary floods in the Lee Valley, thereby removing one of the causes of difference between the Local Board and their tenant.

RAILWAY NOTES.

THE long-projected railway bridge over the Hoogly, which will enable the East India Railway to be run direct into Calcutta, is, it is stated, to be taken in hand immediately. The main features of the bridge is three wrought iron girders, each 400 feet long. The cost will be £275,000, and will be borne by the Government. The work will occupy three or four years.

EARL DELAWARE will, during the approaching session, introduce a bill the object of which is to make the use of continuous brakes on railways compulsory. It will be proposed that after the 1st of February, 1885, every company shall have in connection with each passenger train a continuous brake, which shall be efficient in stopping the train, instantaneous in action, and applicable without difficulty. It must also be immediately self-acting in case of accident, capable of being easily removed, and be of durable material. The brake in each vehicle of a train is to be susceptible of being worked as part of one system. The Board of Trade is to have power to inspect rolling stock, especially with a view to the use of the brake.

IT is estimated that 7500 miles of new railway were constructed last year in the United States; and, according to the Philadelphia correspondent of the *Times*, no less than 18,000 miles of new railway are projected for the current year. A comparison of the new mileage of 1881, with that of each of the previous nine years shows the following result:—1872, 7340 miles; 1873, 3883 miles; 1874, 2 25 miles; 1875, 1561 miles; 1876, 2460 miles; 1877, 2303 miles; 1878, 2916 miles; 1879, 4430 miles; 1880, 5839 miles; 1881, 7500 miles. Capital is thus being set fast in new railroad undertakings, with greater rapidity than during the railway mania which culminated in 1872. It is true that now the States are much better populated and far wealthier than they were nine or ten years ago; they thus need and can afford to provide much more ample means of communication.

IN concluding his report on the collision which occurred on the 9th of December, near the Manchester Central Station of the Cheshire Lines Committee during a thick fog, Major General Hutchinson says: "The speed would certainly have been far more rapidly reduced, and the collision have been mitigated in its results or altogether avoided, had the engine and tender as well as the train been fitted with a quickly acting continuous brake." It has now been decided to apply air brake fittings to the Manchester, Sheffield and Lincolnshire Company's engines and tenders, as well as to the vehicles composing the train The Chester train was forgotten after it had passed out of sight of the signalman at West Cornbrook Junction, and this fact, he says, calls attention to the expediency of some means being adopted to guard against this contingency. He suggests that "in cases of this kind, where a train or engine is stopped from fog or other causes out of sight of a signalman, the guard or fireman should be instructed to go back to the signal cabin, and remain there until the signalman is able to allow the train or engine to proceed."

ORDNANCE AND NAVAL.

THE s.s. Jacob Christensen, which has been built by Messrs. Raylton, Dixon & Co., Middlesborough, to the order of Hans Konow & Co., of Copenhagen, has proceeded on her trial trip. She is a handsome iron screw steamer, 269 feet long, 34 ft. 9 in. beam, 24 ft. 3 in. depth of hold, which gives her a carrying capacity of 2,500 tons on 22 feet draught. She

is built as a three-decked steamer, having main deck of iron and upper of wood. Her water ballast is contained in a large chamber in the main hold forward of engine room, which is also available for storage of cargo. She is fitted with a short poop aft, in which are commodious cabins for captain, officers, and two or three passengers. Higginson's steam quarter master steers her from the bridge, and she is fitted with steam winches and self-reefing topsails. Her engines, of 150 horse power nominal, are by Messrs. T. Richardson and Son, of Hartlepool, and gave every satisfaction on her trial trip.

MOUNTAIN HORSE ARTILLERY.—In the Russian Army List may be found two batteries bearing this description. One of these has been stationed in Turkestan since 1876, and the other (which has only recently been formed) is in Western Siberia. A long article was published in the *Artilleriesky Journal* of October, 1881, on this artillery, which was designed to accompany cavalry in the most mountainous districts, where ordinary artillery could not travel. The guns are three-pounders of the regulation pattern, and are mounted on mountain carriages, the trail of which is attached to a limber of special construction. This latter consists simply of two wheels, on the axle of which is mounted an iron basket capable of containing two ammunition boxes, each holding seven rounds. To the axle is attached an ordinary field artillery pole. Four horses are employed, driven in pairs in the ordinary way. The ammunition wagon is of similar construction to the limber, but the basket is made to carry four ammunition boxes. It is furnished with double poles, and drawn by three horses abreast. All the draught horses are furnished with pack saddles, upon which can be transported the guns and equipment, should it be necessary to dismount them for transport over country where wheeled vehicles could not pass. All the men are mounted, and their saddles are so arranged as to carry the wheels, poles, shafts, whipple trees, &c.; seventeen men are attached to each gun, the corporal of the gun, ten gunners, three drivers, and three horse-keepers. Four of the gunners are considered as reserve, to replace those who may be disabled in action. To every two guns (which form a section of a battery) are a sergeant and trumpeter, and four reserve horses, giving a total for two guns of thirty-six men and forty-eight horses. In November, 1880, a section attached to a special detachment of cavalry made an eight days' march across the Kopet Dagh mountains. Each day they traveled fifty versts, and on the last day of the march eighty versts were accomplished. A short time afterwards this section took part in the attack of Geok Tepe, and is said never to have hampered the movements of the cavalry, but rather to have been a valuable auxiliary. Still the construction of the material left much to be desired. When the guns and carriages were mounted on the pack saddles the men had to dismount and lead their horses; and as, of course, this only occurred in the most difficult country, the speed and length of the marches were limited by the endurance of the men. Moreover, it was only possible to carry forty-two rounds for each gun. The writer of the article proposes several modifications, which he considers will obviate these objections. The carriages, limbers, and wagons must be constructed in such a manner as to be easily dismounted into a number of pieces, so as to reduce the load for each horse, and to enable the men to ride instead of leading the horses. He also considers it indispensable to alter the construction of the ammunition wagon. This he proposes to do by attaching it to a limber similar to that of the gun. This would increase the number of rounds to fifty-six, whilst permitting the same system of draught to be employed as that which proved satisfactory with the gun. This latter could easily pass over obstacles which proved insurmountable to the wagon with its three horses abreast.

THE new tea steamer, the "Stirling Castle," built by Messrs. John Elder & Co. for Messrs. Thos. Skinner & Co., was tried in the Clyde on March 17th and 18th, and gave a speed which shows her to be the fastest ocean-going steamer in the world. In the course of a run of six hours on Friday, she gave an average speed of 18.18 knots, and on Saturday six consecutive runs at the measured mile gave a mean speed, calculated on the Admiralty method, of 13.418 knots, or $21\frac{3}{10}$ miles per hour. The actual time taken in running each mile respectively was 3 min. 13 sec.; 3 min. 23 sec.; 3 min. 12 sec; 3 min. 18 sec; 3 min. 13 sec.; and 3 min. 18 sec. On the trial there was a cargo of 3000 tons dead weight on board ready for the voyage out. Her length is 430ft., breadth 50ft., and depth 33ft., and she registers 4300 tons. Her engines are the three-cylinder type, and have developed 8237-horse power. The diameter of the high pressure cylinder is 62in., and the two low pressure 90in., with a 5ft. 6in. stroke. Surface condensers are used with Gwynne's "Invincible" circulating pumps. The boilers are of steel, and present a total heating surface of 21,161ft.; the grate surface is 787 square feet; and the working pressure 100 lbs. to the square inch. The propeller is made of manganese bronze, is 22ft. 4in. in diameter, with a pitch of 31ft. The maximum number of revolutions at the trial was 66½ per minute, accompanied by absolutely no vibration, except in the immediate vicinity of the screw shaft. The hull is built of steel, on plans approved by the Admiralty, with a view to national requirements, and is capable of carrying coal for a twenty days' cruise. Great interest is attached to the performance of the vessel, as she may be regarded as first favorite in the annual tea race.—*Engineer.*

GERMAN BRONZE GUNS.—The German artillery possesses seven different types of weapons of this material, the heavy 9-centimeter and 12-centimeter guns, the short 15-centimeter gun, the 15-centimeter gun with flat wedge breech-block, the 9-centimeter and 15-centimeter mortars, and the 21-centimeter howitzer, which is only now in course of construction. The heavy 9-centimeter gun has a round

wedge breech-block, with the 1873 pattern safety ring. The vent tube passes through the tube and breech block. A special iron carriage has been made for fortress purposes, but the gun can also be used with the ordinary field carriage. The heavy 12.centimeter gun is of similar construction, but with copper fittings for the breech block. The carriage is formed of two iron frames strengthened with ties riveted on the inner sides. Five degrees of depression and 43 degrees of elevation can be attained. The projectiles have five copper windage rings. The 9-centimeter mortar has a screw breech-block, in which is the powder chamber. The vent tube—which is vertical—passes through the block. No elevating screw is required, the weapon being balanced on the carriage, which consists of two wooden frames secured by three bolts. On the front one of these bolts is the sight, and an elevation scale is attached to the hinder one. This carriage (which has no wheels) has the advantge of a very large base, with its center of gravity very low. The 15-centimeter mortar (which is not yet completed) will be similar in construction. No details of the design of the howitzer are to hand, as the construction has not yet been definitely decided.

The following are the more important weights and measurements:

—	9-cm. Cannon.	12-cm. Cannon.	9-cm. Mortar.	15-cm. Mortar.
Caliber in millm'tr's	88	121	88	
Length of bore.....	....	9ft. 2½in.	20 in.	
Number of grooves	24	30	24	
Weight of gun complete.....	8 cwt.	25½ cwt.	2 cwt.	
Total weight of gun and carriage.....	24 cwt.	45 cwt.	4 cwt.	
Weight of charge..	3.3 lb.	7.7 lb.		
Weight of common shell..	15.4 lb.	35 lb.	15.5lb.	39 lb.
Weight of shrapnel	18 lb.	43.12 lb.		
Weight of bursting charge of common shell	9.85 oz.	2.27 lb.	9.85oz.	4.18lb.
Weight of bursting charge of shrapnel	8 oz.			
Initial velocity of common shell ...	1480 ft.	1433 ft.		
Initial velocity of shrapnel.....	1390 ft.	1300 ft.		
Extreme range of common shell....	7700 yds.	8350 yds.		
Extreme range of shrapnel	2750 yds.	4600 yds.		

MACHINE GUN TRIALS.—Experiments have recently been made in France with the English Admiralty pattern Nordenfelt machine gun, with a view of enabling the French authorities to compare its efficiency with that of the far heavier Hotchkiss revolving cannon, throwing explosive shells of over 2 lbs. weight, as against the Nordenfelt 7 oz. solid steel bullet, previously adopted by the French Admiralty. The experiments were carried out with the greatest secrecy; but we (*Morning Post*) hear from Cherbourg that the French authorities are no longer so satisfied with their anti-torpedo boat gun, of which they have purchased some 600, as they were prior to these trials. It is asserted in Cherbourg that the Nordenfelt English Admiralty pattern machin-gun will be added to the equipment of several classes of French war vessels. The Nordenfelt works are now turning out an improved shell firing gun capable of firing from 15 to 30 rounds a minute. This gun does not weigh a fourth of the weight of the Hotchkiss revolving cannon. Its muzzle velocity and penetration are, however, vastly superior to anything of the kind as yet produced, and the recent trials made at Portsmouth by the Admiralty have proved that this gun is far superior in every way to the Hotchkiss revolving cannon. The Austrians recently used their Nordenfelt naval guns, throwing 7 oz. solid steel bullets, against the insurgents with good effect. But firing such projectiles at men scattered over a large extent of country is somewhat similar to firing heavy ordnance solid shot at sparrows. Explosive shells are required on such occasions and when the guns have to be worked on land, in a mountainous district especially, the lighter they are the better. The Hotchkiss revolving cannon weighs somewhat over a ton, the Nordenfelt shell-firing gun under five hundred weight, a difference in weight which renders the latter gun by far the most serviceable.

IRON AND STEEL NOTES.

KRUPP'S WORKS AT ESSEN.—This establishment was founded in 1810 by the father of the present proprietor, and in 1848 it employed 74 workmen. At the present time about 17,000 persons are engaged. There are at work 1,542 furnaces, 294 boilers, 82 steam hammers varying from 2 cwt. to 50 tons, 310 steam engines of from 2 to 1,000 horse power each, giving a total of 12,000 horse power, and 1,622 machine tools. In addition to this there are 14 blast furnaces, producing 600 tons of pig iron in twenty-four hours. The average daily consumption of coal and coke (including the blast furnaces and several steamers) is 2680 tons. The transport of the material used in the works employs 23 locomotives, 767 wagons, running on 42 miles of track, 50 horses, and 206 carts, while communication between the various departments is maintained by 43 miles of telegraph wires, with 35 stations. The mines belonging to the firm consist of 4 collieries, 547 ironstone mines in Germany, and a large number in the north of Spain. Their daily output is 3,000 tons of coal, 1,600 tons of iron ore, of which 1,200 tons are raised in Germany. The transport of the Spanish ore occupies five steamers belonging to the firm, with a tonnage of 7,800 tons.—*London Mining Journal.*

THE MANUFACTURE OF SOFT STEEL.—At Redbrook Works, Monmouthshire, on Friday last, in presence of an influential gathering of tinplate owners and others interested in the trade, some experiments were conducted in the new converter, patented by Mr. T. Griffiths of Blaenavon, which is intended for the production of soft steel suitable for tinplate. It is a fixed, upright converter of very simple construction, and costs very little in com

parison with the other steel-making plant. The chief novelty lies in the arrangement and construction of the tuyeres, coupled with the use of low-pressure blast, 4 lbs. to the square inch. The steel made was of excellent quality, and some plates were shown made from a former blow, which were everything that could be desired and free from streaks or spots. It is admitted by most authorities that steel is suitable for nearly all purposes to which iron has hitherto been applied. We have an exemplification of this in the manufacture of tin bar and soft steel bars, producing less waste and cleaner plates, so that this converter should find favor with plate makers on account of its low cost, simplicity, and the excellent quality of steel.—*London Colliery Guardian, March* 10.

THE iron and steel exports from Great Britain amounted last year to 3,818,338 tons. In 1880 it was 3,787,271 tons. The imports of iron, iron ore, steel, and tin in the same years were 2,587,981 tons in 1881, and 2,779,958 tons in 1880. The value of exported iron, steel, machinery, hardware, &c., was £42,381,662 in 1880, and £43,353,021 in 1881.

TEMPERING BY PRESSURE.—A new method of tempering metals has been brought to the notice of the French Academy of Sciences by M. Clemandot. It consists in heating the metals to a cherry red and then compressing them strongly and maintaining the pressure until they have completely cooled. Metals thus treated acquire a great hardness and so fine a grain that when polished they resemble nickel. Compressed steel, like tempered steel, takes the coercive force which gives it the property of being permanently magnetized. As regards the duration of the magnetism, M. Clemandot states that the magnets of the Gower, Bell, and Ader telephones made of this new steel several moths ago have thus far preserved their force. As in ordinary tempering, M. Clemandot thinks the new process produces an amorphism in the metal; and he points out that it will now be possible to graduate a temper by graduating the pressure applied. In experimenting with different steel he finds those of Allevard always the best for magnetic purposes. Elliptical bars of steel seemed to take the pressure in all their parts, and showed a uniform fracture thoroughout. M. Clemandot's interesting discovery is likely to prove useful in the arts, and to open up a new field of study to electricians and metallurgists.

THE FUTURE OF IRON.—The following passage, taken from an article on "Dephosphorization in the Converter," by M. Walrand (late manager of the Creuzot Steel-works, now of the Valenciennes Steel-works), which appears in the recent issue of the *Revue universelle des Mines*, deserves attention, as showing the views of a practical man on the immediate future of iron. M. Walrand observes:—"Those who are occupied in the manufacture of Bessemer steel know how difficult it is to obtain with regularity the extra soft steel employed for boilers in the French navy. Such metal appeared only to be made in the Martin furnace, and even then it was necessary to employ picked material in its manufacture. But by the new Bessemer dephosphorizing (Thomas-Gilchrist) process steels of an extraordinary degree of softness can be obtained with the greatest facility, and at a price less than that of ordinary rail steel. By treating a pig containing from 1.5 to 2 per cent. of manganese, we obtain, after the decarbonization and dephosphorization is finished, a non-oxydized metal which does not contain more than traces of carbon or manganese. If it be desired that the steel should be entirely free from any tendency to redshortness, we may add from 0 25 to 0.50 per cent. of a rich ferromanganese to remove any traces of oxygenization. The only precaution to be taken to obtain a soft steel is to choose pig (if direct working be employed) which contains sufficient manganese (with 2 per cent. as a maximum) or to make a suitable mixture of pigs if cupolas be employed. But this will be by no means the only outlet for dephosphorized metal, for up to the present time the high price of soft steel has been the great obstacle which has prevented many people from employing it in construction. But, by the new process, soft metal can be produced at a less price than ordinary (puddled) iron; there is, therefore, no longer any reason (apart from routine) why steel should not be employed in all cases in place of iron, to which it is so much superior in strength."

BOOK NOTICES.

PUBLICATIONS RECEIVED.

MINUTES OF THE PROCEEDINGS OF THE INSTITUTION OF CIVIL ENGINEERS:

The Conservancy of Rivers. By William Henry Wheeler, M.I.C.E., and Arthur Jacob, M.I.C.E.

The Forces and Strains of Recoil. By Henry Joseph Rutter, M.I.C.E.

Iron Permanent Way. By Charles Wood, M.I.C.E.

Harlacher's Current Meter. By Richard Bloom.

HISTORY OF THE WATER SUPPLY OF THE WORLD. By Thos. J. Bell. Cincinnati: P. G. Thomson.

PROCEEDINGS OF THE SOCIETY OF ARTS.—Boston, Mass: Institute of Technology.

SCIENTIFIC PROCEEDINGS OF THE OHIO MECHANICAL INSTITUTE.

CONSTITUTIONS AND BY-LAWS OF THE DENVER SOCIETY OF CIVIL ENGINEERS.

AMERICAN JOURNAL OF MATHEMATICS.—Baltimore: Johns Hopkins University.

TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS. Advance sheets.

REPORT ON A WATER SUPPLY FOR NEW YORK AND OTHER CITIES OF THE HUDSON VALLEY.—By J. T. Fanning, C.E.

A Systematic Handbook of Volumetric Analyses.—By Francis Sutton, F.C.S. Fourth Edition. Philadelphia: Presley Blakiston. Price $5.00.

In the interval between the exhaustion of the third edition of this valuable book and the appearance of the fourth, the demand for the book was such as to bear strong testimony to the high estimate placed upon it by chemical students.

This edition is an improvement upon the old by reason of extensive revision and additions.

The author's methods are known and used wherever there are analytical chemical processes.

Candle Power of the Electric Light. By Paget Higgs, LL D. New York. E. & F. N. Spon. Price 75 cts

This is a good enough book, what there is of it, which is very little. The little will prove attractive to a large number, because it relates so directly to one of the most important questions of public and also of domestic economy. But we are inclined to believe that the buyers everywhere will feel that both author and publisher have rated the essay above its value.

Musical Acoustics. By John Broadhouse. London: Wm. Reeves. Price $3.00.

This is a book for students, and presents in a an able manner all that the average student needs of the larger works of Helmholtz. It is well arranged and fully illustrated.

A Practical Treatise on Hydraulic and Water-Supply Engineering. By J. T Fanning, C. E. Third Edition. New York: D. Van Nostrand. Price. $5.00.

This treatise is too well known to require an extended notice at this time. The fact that a third edition was demanded is sufficient evidence that the work is widely appreciated. It has long since become a familiar standard for reference. The three sections of the work are:

The collection and storage of water and its impurities.

Flow of water through sluices, pipes and channels.

Practical construction of water works.

Each of these is a complete practical treatise in itself.

The Elements of Modern Tactics. By Wilkinson J. Shaw, M.A. Third Edition. London: Kegan Paul, French & Co. Price $3.50.

This forms the second volume of "Military Handbooks for Officers and Non-commissioned Officers."

The value of the book is enhanced largely by the excellence of the illustrations.

The separate chapters present in order the following topics:

Introduction—Functions of the three arms—Security and Information—Reconnoitering—Attack and Defense of Cavalry—Attack and Defense of the three arms—Rear Guards.

The book is of convenient size, and is well printed.

MISCELLANEOUS.

The Dephosphorization Process.—Doubts have recently been expressed as to the commercial success of the Thomas-Gilchrist dephosphorizing process, and it has been especially emphasized that the use of hematite ores has not been restricted by the basic process, but that, on the contrary, those ores are still largely employed. To this it has been replied that even the inventors of the new process have never dreamt of entirely superseding the Bessemer process by theirs; and Mr. Brauns, at a recent meeting of the German Iron and Steel Institute, expressly stated that the acid process, wherever suitable ores are obtainable, will keep its own as against the basic process As to the commercial success of the latter process, Mr. Thomas in a recent letter to us, cited facts which set at rest all doubts on the point. The *Essener Zietung*, arguing in support of that view, says that from those undeniable facts, it is evident that the commercial success of the dephosphorization process can no longer be denied. The apprehension, however, that the few German ores containing little phosphorus could be depreciated in value, is, according to our contemporary, entirely groundless. Already at the meeting of the German Iron and Steel Institute above referred to, attention was drawn to the fact that the manganiferous spiegeleisen of the Siegen district is as valuable for the manufacture of Thomas steel as of Bessemer steel. This value can only increase with the extension of steel-making.

The Potentials of Electric Sparks.—Sir William Thomson has made a great many experiments on the difference of potentials corresponding to electric sparks of different lengths across the air; but, a recent investigation of M. J. B. Baille on the same subject, but with somewhat longer sparks, furnishes results which are not quite in agreement with those of Sir William. The potentials of the latter physicist corresponding to sparks of a certain length are slightly less than those obtained by M. Baille for the same length of spark, and the discrepancy is attributed by M. Baille to Sir William Thomson having used a conductor which was constantly discharged by a continuous series of sparks, so that the potential was continually varying very rapidly, and only an intermediate value, somewhere between the maximum and minimum, could be obtained. M. Baille, though employing an absolute electrometer to measure the potentials, as did Sir William Thomson, took care to keep the difference of potentials constant during the measurements, by using a condenser that only gave sparks at long intervals. The potential was thus a maximum slowly attained, and the attraction also became a maximum at the moment of sparking. His results show generally that the potential of an electrified plate increases almost regularly with the sparking distance. The electric densities corresponding to different sparks decrease at first slowly and soon arrive at a constant value as is already known. The pressure exercised by the elec

tricity on the air at the sparking moment for a distance of one centimeter is ony $\frac{1}{3000}$ of the atmospheric pressure. We may add that the difference of potentials, as found by M. Baille, for a spark of 0.0025 centimeters is 1.90, that for 1 centimeter 14 67, that for 5 centimeters is 54.47, and that for 10 centimeters is 105.50 units.

REFLECTED ELECTRIC LIGHT.—The experiments which have been conducted on board the *Sultan* at Portsmouth, with a view of ascertaining whether the electric search lights in men-of-war could be protected from the guns of torpedo boats by the adoption of reflected light under cover, have been concluded. The official trial was witnessed by officers from the Admiralty and the War Department and from the local Torpedo School. Four different kinds of lenses were tested for purposes of comparison, the intensity of the electric beam being measured by a Bunsen's photometer and one of Sugg's burners. The apparatus used were a dioptric lens, a catoptric lens 90 centimeters in diameter, the ordinary «bovebord »hip's glass, which was similar in character, but only 60 centimeters in diameter, and a reflector made of Chance's glass and silvered. The respective merits of each were found to be in the order mentioned, the dioptric producing double the illuminating power of the next best, and with an appreciable economy in cost.

THE uses of asbestos increase every year. Asbestos, in the form of a felt or tissue, is said to make a flood filtering medium for the chemical labratory, as it resists the action of corrosive acids as well as of fire. For the same reason, a pair of gloves woven from this substance is useful for handling acids. A sheet of asbestos card covering the table preserves it, and also prevents the breakage of small glass objects. Asbestos makes excellent porous cells for a galvanic battery; and kneaded with plastic clay affords a good luting for the stoppers of bottles. Asbestos paint, used to protect objects from fire, has also been lately manufactured.

FOR diminishing the danger of conflagrations in theatres, Signor Giovanni Abelo Martin recommends the following formulæ for rendering materials non-inflammable in the three cases below:—Mixture suitable for light tissues: Pure sulphate of ammonia, 8 parts; pure carbonate of ammonia, 2½ parts; boracic acid, 3 parts; starch, dextrine or gelatine, 2 parts; water 100 parts. (2) Mixture suitable for scenes already painted, timber work, furniture, doors and windows, to be applied like paint with a brush, at a temperature of about 140 deg. Fah.: Hydrochlorate of ammonia, 15 parts; boracic acid, 5 parts; glue, 50 parts; gelatine, 1 part, water 100 parts. (3) Mixture suitable for cloths, ropes and straw, which should be immersed for fifteen or twenty minutes, at a tempera ure of 212 deg. Fah., and allowed to dry. Hydrochlorate of ammonia, 15 parts; boracic acid, 6 parts; borax, 3 parts; water, 100 parts.

SOME time since the German Society for the Promotion of Industry offered a prize of 2000 marks for the best manganese alloys, with a view to obtain samples which might be tested for their physical qualities, especially their tensile resistance, and by this means to ascertain the influence of manganese on iron. The competitors were the Gutehoffnungs Iron Works, Oberhausen, and R. Selhof, engineer of the cast steel and arm factory, Witten. No less than 20 iron rods were required, which had all to be 50 centimeters long and 40mm thick. The first lot was to consist of an alloy of manganese and iron, of which the carbon did not reach 0.6 per cent., and all other substances were not allowed to exceed 0.4 per cent. The second set was to consist of carbon containing an alloy, manganese and iron, in which all other substances were not allowed to exceed 0.6 per cent. The chemical analysis and tests show that it is very difficult to mix alloys or different sorts of iron, that manganese is very easily oxidized and disappears from the alloy, and that when the rods were worked in a lathe or with a plane, and prepared for the tearing tests, they exhibited a large number of spots, showing that the amalgamation was imperfect. Notwithstanding that the results were not in accordance with the conditions, the society agreed to award the prize to the competitors on account of the trouble they had taken. The Gutehoffnungsbutte having come nearer the conditions, was awarded two-thirds and Selhoff one-third of the prize offered.

WHAT would be the relation between the velocities of clouds of smoke and gusty wind by which they were impelled? The value of the following which was sent by a correspondent to *Nature*, somewhat depends on this question. He reports the following observations on the velocity of the wind in the southwest gale on the 21st, and 22nd of November last, at Edinburgh: "The observations were made about 9 o'clock on the morning of the 22d, when the wind had somewhat moderated: Mean velocity, 62.3 miles per hour; during a squall, 61.6. These observations he calculated from clouds of smoke issuing from the chimney of the Caledonian Distillery, and traveling for a distance of 2108 feet, and are thus free from instrumental errors. The chimney is 225 feet high, and its base about 200 ft above the sea level. During the gales on the 14th the recording anemometer at the Greenwich observatory registered a wind pressure of 57 pounds per square foot, the highest ever recorded there. Prof. Robert Grant, F. R. S., who occupies the chair of Practical Astronomy in the University of Glasgow, reported that during the violent storm which passed over that city on the night of November 21st, and the following morning, during several hours after the special observations commenced, the velocity of the wind ranged from 16 miles to 17 miles, but at 11 p. m. it had risen to 30 miles, and it went on increasing till 2 o'clock next morning, when the register indicated a velocity of 54 miles an hour, and the reading at 6 o'clock was 57 miles an hour. Just a few minutes before 11 o'clock there was a tremendous gust of wind, which, measured by Osler's anemometer, was equivalent to a wind pressure, as already mentioned, of 48 lbs. on the square

foot. This was confirmed by the indications of Robinson's velocity anemometer, which showed that for a few minutes the wind was traveling at the rate of nearly 80 miles an hour.

A NEW ELECTRIC CURRENT METER—At the Physical Society, on January 28, Mr. C. Vernon Boys read a paper on an apparatus for measuring the strength of an electric current, which, so far as we are aware, is highly original. The rate of a pendulum clock depends on gravity, and is proportional to the square root of the strength of gravity. The rate of a watch depends on the strength of the hair spring, and is proportional to the square root of the hair spring. The force due to a current passing through any combination of wires and iron is proportional to the square of the current strength. If, then, any of the parts of the combination are arranged so that they vibrate under the influence of an electro-magnetic force, the speed of vibration will be simply proportional to the current strength, because the square of the speed measures the force, and the force is proportional to the square of the current. Let such a contrivance take the place of the balance or pendulum of a clock, and the clock will become a measurer of the quantity of electric current instead of time. In order that the indications should be true, either the maintaining power must be so contrived that the amplitude does not vary much, in which case it does not matter what the law is connecting the force with the displacement, or the parts must be so arranged that the force is directly proportional to the displacement, in which case it does not matter what the amplitude is. The two important points, therefore, are the controlling and the maintaining powers. M. Boys showed several ways of producing a controlling power In the first case, which was a combination of two solenoids, one moving through the interior of the other, the force will, if they are properly arranged, be proportional to the displacement. As there is no iron in this arrangement it will apply to the case of alternating currents. In another case a small armature is mounted on the balance staff, and around it are the two poles of an electro-magnet which forms part of the circuit. Another form is unaffected by residual magnetism. In it two crescent-shaped pieces of iron forming the sides of the balance pass through two fixed solenoids. The iron pieces are carried by a cross arm mounted on a vertical spindle, and they serve to form sectors of a circle like the balance wheel of an English lever watch. By passing the current through the coils, the cores are attracted into the latter, and if the current diminishes or increases in strength, the cores will retire or advance within the coils. In all these cases the direction of the current is of no consequence. The maintaining power may be an ordinary escapement driven by clockwork in the usual way. In this case the amplitude will be less with a stronger current; but this drawback may be overcome by the use of an electro-magnetic *remontoire*. The maintaining power can, however, be independent of clockwork if an impulse is given to the electricity at each swing of the balance. Mr. Boys exhibited a meter constructed on this principle for him by Messrs. Elliot Brothers. The controlling power in it depends on iron crescents mounted like parts of a watch balance wheel on a vertical spindle, and each enclosed by a pair of solenoids consisting of a primary and secondary coil. The main current runs through the primary solenoids, but a portion of it is diverted through the secondary solenoids when the balance is its neutral position, at which time a variation of the current in the controlling solenoids has no effect in disturbing the period of an oscillation. To regulate meters of this class, a weigher is screwed outwards or inwards, according as the meter goes too fast or too slow. As this meter depends on dynamical principles alone, and is independent of gravity, it must work equally well wherever it is planted.

ON a recent occasion Dr. Grant, of Glasgow, gave an interesting summary of the present state of the science of meteorology. In the course of his remarks he said :—"The Meteorological Office, originally a branch of the Board of Trade, commenced its labors in 1868, the council of scientific men, under whose direction it is conducted, being nominated by the Royal Society. There are three leading objects which the council have kept in view since 1868. These are :—(1) Ocean Meteorology ; (2) land meteorology of the Britis Isles ; (3) weather telegraphy. Seven observatories have been established in connection with the Meteorological Office, with a view to the advancement of the land meteorology of the British Isles These are the observatories of Valentia and Armagh, in Ireland ; Falmouth, Kew and Stonyhurst, in England, and, finally, Glasgow and Aberden, in Scotland. The observations at each of these observatories are all obtained by means of self-recording instruments, and the tabulated results are regularly transmitted once a week to the Meteorological Office in London. The variations of the barometer and of the dry and wet bulb thermometers are recorded continuously upon paper by a photographic process which goes on night and day without intermission. The velocity of the wind is measured by Dr. Robinson's anemometers. The mean hourly velocity of the wind for the three years 1874, 5-6 was:—for Armagh, 10.6 miles, 10.0 miles, and 9.8 miles ; for Kew, 10.3 miles, 10.8 miles, and 10.8 miles ; for Stonyhurst, 10.8 miles, 10.9 miles, and 10 7 miles ; for Glasgow, 12.9 miles, 12.9 miles, 12.1 miles, and 12.4 miles ; for Aberden, 13.3 miles, 13.5 miles, and 14.2 miles; for Falmouth, 16.8 miles, 17.0 miles, and 17.4 miles ; finally, for Valentia, 18.2 miles, 17.7 miles and 17.9 miles. During the last two or three years as many as 75 per cent. of the storm warnings which have emanated from the Meteorological Office have been thoroughly successful. During the storm of Friday, the 6th ult. Osler's anemometers recorded a pressure of 51 lbs. on the square foot, and yet it bore the strain admirably. During the great snowstorm which swept over London and its neighborhood on the 18th January, 1881, the Osler anemometer at the Royal Observatory, Greenwich, registered as high as 51. lbs. on the square foot."

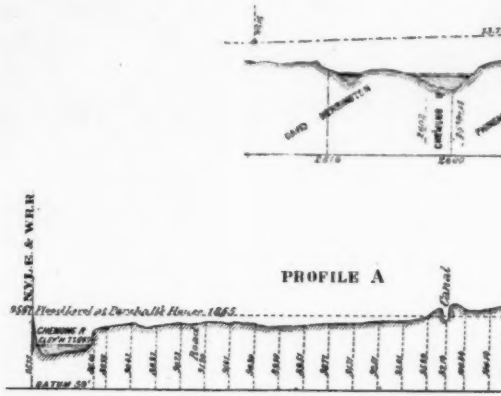
SURVEY MAP AND PROFILES

OF THE LOCATION OF THE ROUTE OF THE

NEW YORK LACKAWANNA & WESTERN R.R

IN THE TOWN OF

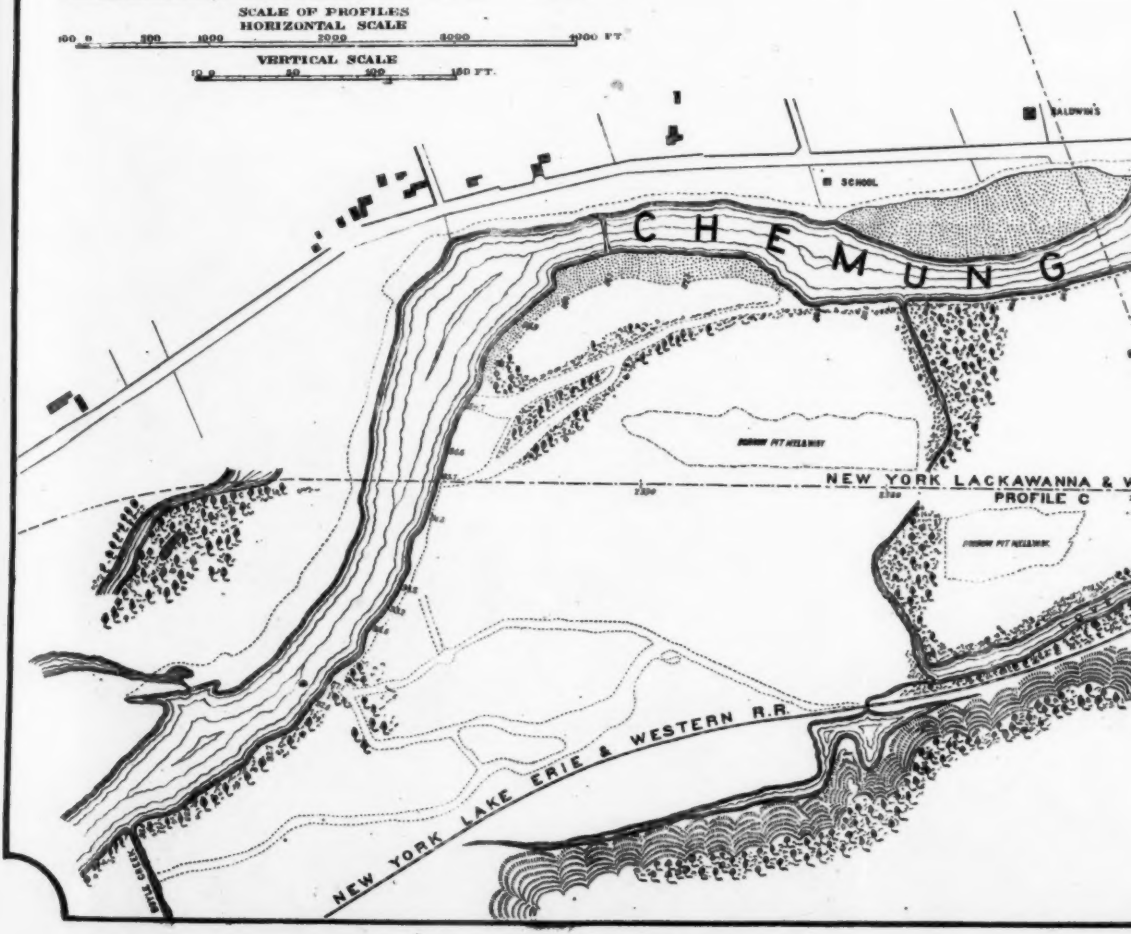
CHEMUNG N.Y.

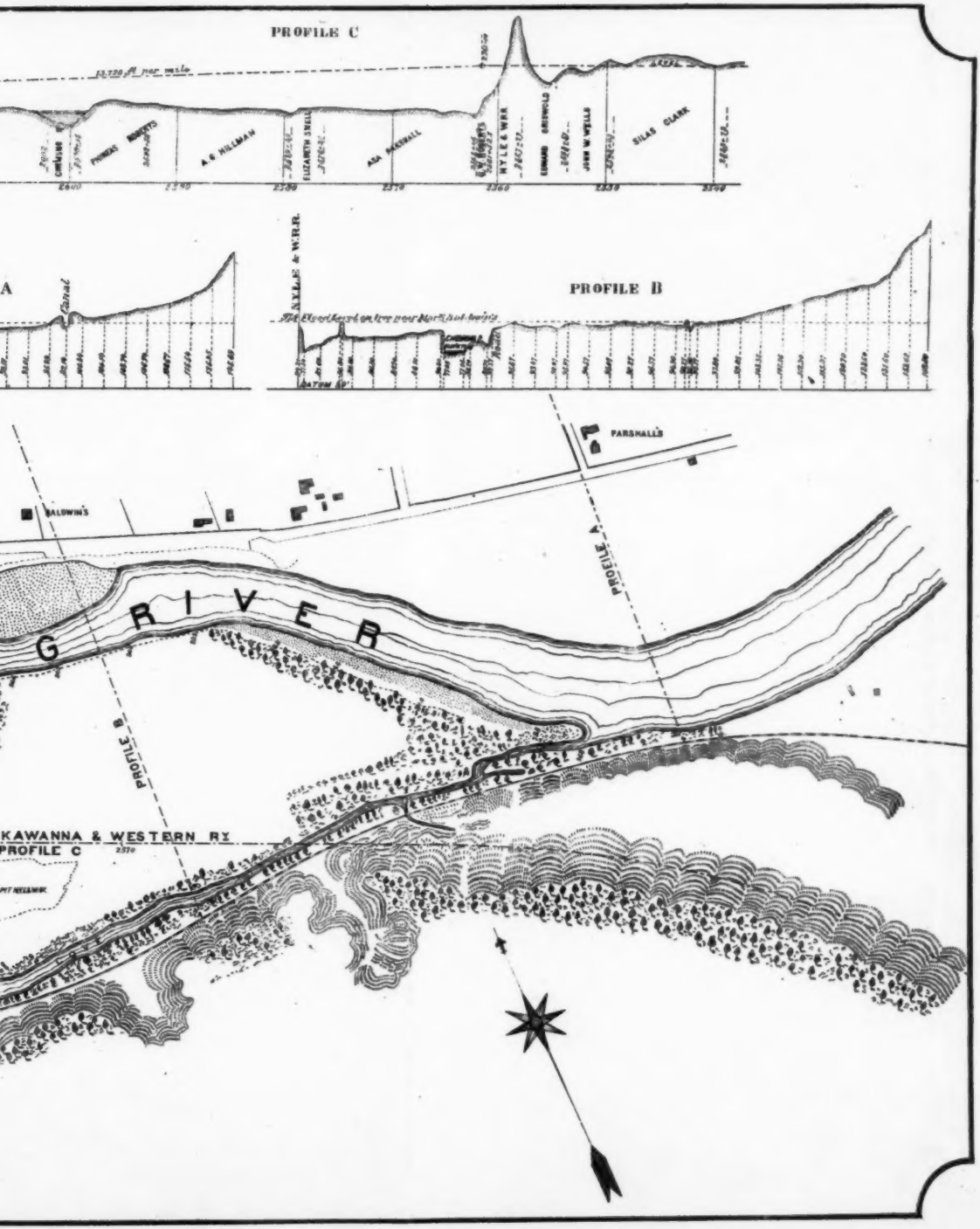


SCALE OF MAP
100 0 500 1000 1500 2000 FT.

SCALE OF PROFILES
HORIZONTAL SCALE
100 0 500 1000 2000 3000 4000 FT.

VERTICAL SCALE
10 0 50 100 150 FT.




PROFILE C
PROFILE B
PROFILE A
PARSHALL'S
BALDWIN'S
G RIVER
PROFILE A
PROFILE B
KAWANNA & WESTERN RY
PROFILE C